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COMPARATIVE EVALUATION OF INSULATING SEALED GLASS UNITS

Undertaken jointly by the Ontario Ministry of Municipal Affairs and Housing and the Ontario Ministry of Energy under the Housing Energy Management Program (H.E.M.P.)

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EXECUTIVE SUMMARY

Sealed insulating glass window units were tested at Ontario Research to evaluate seal durability, thermal and sound attenuation performance on a comparative basis for different combinations of seal materials and configurations, number and spacing of glazings, and presence of gas fills. The objective was to generate technical data suitable for consumer use as an aid to choosing among the many products available in the market place.

From analysis of the test results, relative thermal performance trends are apparent with respect to the type of edge seal, air space size and presence of gas fill in the units. The largest reductions in thermal loss were recorded by changing from single to double glazing. The units with 6.35 mm air space achieved 63% reductions, and those with 12.7 mm achieved 70% reductions. A further thermal loss decrease was achieved by changing from double glazing to triple glazing. These reductions were 24% for 6.35/6.35 mm spacing and 31.5% for 12.7/12.7 mm spacing. Heat flow occurring near the edges of the units appears to be sufficiently large to provide an area where meaningful improvements in thermal performance could be made. Additional Heat flow reductions can be achieved by the type of edge seal used and by the use of gas fill. These reductions are of a much lower level than those associated with a number of glazing units.

The degree of sound attenuation provided by a sealed unit, as defined by its Sound Transmission Class (STC) rating, is also directly related to the interpane spacing, number of glazings and the presence of gas fill. Various single and double seal configurations were evaluated for sound insulating characteristics in this series of tests. Single and double glazing units of the 6.35 mm type leave a comparably low sound attenuation. The majority of

other samples were two to three classes better, with the triple glazed 12.7/12.7 mm gas filled unit five classes better than the single. Introduction of gas into a double glazed 12.7 mm sample did not improve the STC rating. The STC rating relates to a sound transmission loss occurring at a standard frequency of 500 Hz and best fits the single glazing sample over the full frequency range. It is important to examine individual frequency loss graphs of each sample to assess its sound transmission loss for specific sound frequencies of interest.

A number of edge seal combinations were tested. The polyisobutylene single seal outperformed thermally the dual sealed units by 4 to 8%. These in turn performed better than the polysulphide single seal units by 11 to 15%. Polyisobutylene is seldom used alone as a seal because of its poor structural qualities, and in the tests exhibited space movement.

As indicated by the two sample configurations that were evaluated for seal durability (18 specimens each of a double glazing and a triple glazing), a third glazing panel affects the ability of a sealed unit to retain its integrity. This results in a significant rise in interior space dew-point, and can most likely be attributed to additional movements and stresses applied to the edge seal by the added glazing and spacer, and increased temperature differentials present as the unit becomes increasingly resistant to heat flow.

Summary of Test Results, With Samples Presented in Order of Increasing Resistance to Thermal and Sound Transmission

Sample Description (see key below)	Thermal Performance			** Sound Transmission	*Seal Durability
	Apparent R_T ($m^2.K/W$)	Heat Flow (W)	Reduction in Heat Flow Over Single Glazing (%)	(STC Rating)	(CAN2 12.8 Rating)
TGU DS GF 12.7/12.7	0.567	54.810	81.1	36	-
TGU PBSS NGF 12.7/12.7	0.562	57.341	80.2	-	-
TGU DS NGF 12.7/12.7	0.543	59.607	79.5	34	-
TGU DS GF 6.35/6.35	0.529	61.261	78.9	33	unsatisfactory
TGU PSSS NGF 12.7/12.7	0.482	66.953	76.9	33	-
TGU DS NGF 6.35/6.35	0.463	69.669	76.0	-	-
TGU PSSS NGF 6.35/6.35	0.402	79.701	72.5	-	-
DGU PBSS NGF 12.7	0.405	79.858	72.5	-	-
DGU PSSS NGF 12.7	0.392	81.844	71.8	33	-
DGU DS GF 12.7	0.380	84.153	71.0	33	satisfactory
DGU DS GF 6.35	0.378	84.348	71.0	30	-
DGU DS NGF 12.7	0.365	87.073	70.0	33	-
DGU DS NGF 6.35	0.351	91.560	68.4	-	-
DGU PSSS NGF 6.35	0.297	107.285	63.0	-	-
SGU - 5 mm glass	0.110	290.010	-	31	-

KEY:
- TGU - triple glazed unit
- DGU - double glazed unit
- SGU - single glazed unit
- DS - dual seal (polysulphide/polyisobutylene)
- PSSS - polysulphide single seal
- PBSS - polyisobutylene single seal
- GF - gas filled
- NGF - non gas filled

12.7/12.7 - interpane spacings of 12.7mm for a triple glazed unit

12.7 - interpane spacing of 12.7mm for a double glazed unit

* 2 configurations - double glazed dual seal and triple glazed dual seal (gas filled) were tested. Satisfactory rating means that after testing, all units retain a dew point below -40°C. 18 samples were tested for each configuration.

** 9 configurations were tested and each assigned a Sound Transmission Class rating, as described in section 2.4.

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1. INTRODUCTION

Tests were conducted in the Building Performance Centre at Ontario Research in conjunction with the Ontario Ministry of Municipal Affairs and Housing - Research and Development section, to evaluate insulating sealed glass units on a comparative basis. As a result of this program, it was possible to compare thermal performance, sound attenuation, and seal durability of double and triple glazed sealed units using a polysulphide and/or polyisobutylene edge seal. The objective of this program was to provide performance and supporting technical data which could be used by consumers to make informed choices among the many types of sealed units presently on the market in Canada.

2. TECHNICAL BACKGROUND AND METHODOLOGY

2.1 General Background

Hermetically sealed glass units are enjoying increased popularity in building design as interest in the energy efficiency of building components continues to grow. Several different types of sealed units are currently manufactured, the method of perimeter seal being a major basis of classification. The most common sealing technique is the holding of glazings together using organic sealants such as polysulphide, polyisobutylene or a combination of both, over a metal spacer containing a desiccant. Other methods are the fusing of glazing edges to produce a glass seal, the use of a lead spacer bonded to the glass by a special soldering technique, a desiccant impregnated organic sealant over a corrugated metal strip, polyurethane or silicone used as an edge seal, or a combination of organic sealants in conjunction with a wrap-around metal edging.

Areas of design or fabrication weakness include corner joints, lateral rigidity of spacers, quality of glass, matching of desiccants to air space size and gas type, and quality of desiccant and sealant materials. Proper pressure control of air spaces and clean, dry manufacturing conditions must be ensured to prevent premature seal failures.

In order to make valid comparisons between available types and configurations of sealed glass units, it is first necessary to establish the basic criteria against which the options can be compared. Assuming the variation in light transmission between single, double and triple glazings to be acceptable, the most important characteristics of these units are energy efficiency (heat flow through the sample), durability, and resistance to the transmission of airborne sound.

2.2 Heat Flow Rates

Sealed units offer superior maintenance characteristics and resistance to condensation over alternative double glazing systems, as well as the potential to increase the thermal performance by the addition of noble gases to the interpane spaces. Thermal performance has become a major concern for sealed glazing units, and can be affected by the spacer material or design, thickness of the insulating space, type of gas in the interpane space, or detail of the seal at the perimeter of the unit. Heat loss is generally greater around the perimeter of the unit due to high conductivity of the spacer. This can lead to differential thermal stresses within the glass being concentrated at a flaw or stress point causing failure.

Any discussion of thermal losses must include a method for measuring these losses. The overall thermal transmittance or U value, of a building component is not an intrinsic property of that element, but rather a heat transfer rate which exists under carefully defined environmental conditions.

The U value of a window is defined by:

$$U = \frac{1}{\frac{1}{h_o} + \frac{1}{C} + \frac{1}{h_i}}$$

where h_o and h_i are the outside and inside air film conductances respectively, and C is the net conductance of the window system. Both h_o and h_i have convective and radiative components, and changes in wind speed and direction, surface emissivities, or surface and air temperatures will modify the values of h_o and h_i. In the case of a single glazing, where the sheet glass has a high conductivity, virtually all of the insulating value is provided by surface air layers. Consequently, the heat flow through a single glazing can fluctuate by $\pm$ 40% with large changes in h_o and h_i.[1]

In a complex window, C may be composed of several series and/or parallel heat flow rates, the sum of which can be measured, using appropriate equipment, to give the overall heat flow rate for the total window system. The thermal resistance R is defined as the inverse of the conductance of the sample. In this program the apparent total thermal resistance R_T (including surface air film resistances) was used to allow a comparative evaluation of the thermal performance of the sample units.

Test Procedure:

During the course of this program, thermal tests were conducted using a guarded hot box apparatus in compliance with ASTM C236 specifications. The units were mounted in a frame in groups of four to allow for expedient testing of a large number of samples. The frame consisted of 102mm of rigid polystyrene insulation laminated together with a 19.0mm plywood surface for structural support. This was in turn mounted into a 2.43 metre square opening in the guard frame of the guarded hot box.

The samples were held in the frame opening using a compressible glass-fibre edging covered with a fabric tape. The edges of the glass units were then sealed to the frame face, again using fabric tape to eliminate air movement around the sample perimeter.

The metering box and thermocouples were equipped with 'quick disconnect' plugs to allow for movement from one sample to the next without disturbing any of the thermocouple placements on either side. This allowed thermocouple placements to be made prior to start-up of the cold side refrigeration unit, and to avoid thermocouple adherence problems due to condensation. The apparatus was arranged as shown in Figure A1 (Appendix A) and the thermocouple layouts are included in Figure A2 (Appendix A).

Test conditions are outlined below.

Test procedure - ASTM C236, 'Heat Flow Measurement of Built-up Wall Sections by Means of a Guarded Hot Box'.

Duration of test - 8 hrs. following steady state (two 4 hour blocks).

Deviation allowances - R_T to within 1%, one 4-hour block to the next. (R_T = air to air apparent thermal resistance)

Nominal cold side temperature (air) $-32^{o}C$
Nominal warm side temperature (air) $+22^{o}C$
A wind machine simulating a 24 km/h (15 mph) wind perpendicular to the cold surface was used during the tests.

A detailed description of the guarded hot box methodology and rationale is included in Appendix A.

To estimate the effect of edge losses, temperature profile grids were set up on four representative samples, two double glazed and two triple glazed units. The temperature differences measured horizontally and vertically, both near the top and bottom of each unit, showed the areas of higher conductance (lower ΔT) around the perimeter of the sealed units.

2.3 Durability

Of primary importance is the service life one can expect to obtain from a sealed unit. The units are subject to a number of forces that cause stress within the glass itself; within the spacer and sealant matrix; and at the interface between glazing and seal. Forces can be applied by wind loads acting on the face of the glass which tend to fatigue the glazing/sealant joint or in extreme cases

can cause structural failure of the glazing[2]. Atmospheric pressure changes or thermally induced volume fluctuations of interpane gas can sometimes cause large pressure differentials between the sealed interpane gas and the ambient atmosphere. This can also cause cycling failure of the spacer/glazing seal, as well as possible glazing failure if the pressure differential becomes too great. Another source of large pressure differential problems can be that of desiccants which become "selective" at temperature extremes. These can absorb specific gas molecules out of the interpane gas causing the interpane pressure to drop dramatically, hence putting additional strain on the perimeter seal and glazing. A third potential problem is the effect of temperature variation and the accompanying differential thermal movement between the components at the perimeter seal. This can damage the seal over a period of time, and in certain cases (such as where an extremely cold sealed unit that is isolated from interior heating by shutters is struck suddenly by solar energy), instantaneous failure of the glazing can occur requiring replacement of the entire unit.

A durability analysis should also include resistance of the seal material to degradation by moisture or ultra-violet light and reactivity with certain interpane gas fills. Lack of stability under these conditions can produce discolouration on the interior surface of the glazings.

Seal or glazing failures result in dirt and condensation being introduced into the interpane cavity, potential loss of thermal or sound resistance, and overall loss of aesthetic appeal necessitating replacement of the sealed unit. For gas filled units, integrity of the seal is also a guarantee that the insulating gas remains in the unit for thermal or sound attenuation purposes.

Test Procedure:

Durability of the sample was determined in accordance with CGSB CAN 2-12.8 "Insulating Glass Units". This test evaluates initial seal; initial dew point temperature; ultra-violet fogging; weather cycling under high and low temperature conditions; and high humidity cycling. The procedure simulates severe temperature, humidity, pressure and cycling stresses that the unit can be expected to encounter in use, and is a practical guide for measuring the durability of a sealed unit. Within the constraints of this program, 2 configurations (double glazed dual seal and triple glazed dual seal) were tested to determine their relative performance and therefore illustrate the durability considerations of adding a third glazing to a double glazed unit.

2.4 Sound Attenuation

The acoustical insulating properties of a window are commonly measured in terms of Transmission Loss (TL) and Sound Transmission Class (STC). Transmission Loss (TL) of a partition, in a specified frequency band is defined as:

> ".. ten times the common logarithm of the ratio of the airborne sound power incident on the partition to the sound power transmitted by the partition and radiated on the other side. The quantity so obtained is expressed in decibels." [3]

Sound Transmission Class (STC) is defined as:

> "a single-number rating derived from measured values of transmission loss in accordance with ASTM E413, Determination of Sound Transmission Class. It provides an estimate of the performance of a partition in certain common sound insulation problems"[4]

Simply put, to measure the acoustical properties of a window, it is placed in a suitable opening between two reverberation rooms. Random noise is introduced into one room and the other is left dormant. Average sound pressure levels are measured in both rooms over a number of 1/3 octave frequency ranges. The difference between the two average levels gives the Transmission Loss (TL), one for each 1/3 octave range. A standardized method of curve fitting produces a single valued representation of the isolating capabilities of the window known as the Sound Transmission Class (STC).

A typical TL vs. Frequency curve is divided into three regions: the stiffness/resonance region, the mass law region and the stiffness/coincidence region. In the stiffness resonance region, the window's isolating characteristics are affected mostly by the natural resonances of plate glass. In the mass law region the isolating properties are governed by the mass law curve. The most obvious aspect of the mass law curve is that when the frequency is doubled, the Transmission Loss (TL) increases 5-6 dB. Another property of the mass law states that if the mass of the isolator is doubled at any given frequency, the TL at that same frequency will increase 5-6 dB[4]. Above the mass law region, TL is controlled by the coincidence effect. Above a certain critical frequency (marked f_c in Figure 1, page 9), the wavelength of the bending wave in the window panel may become equal to the wavelength of the incident sound, depending on the angle of incidence. When this occurs, the window vibrates with the incident wave and acts as a radiator of it[5]. The result of this is a severe dip in TL above that critical frequency.

It should be pointed out that the "typical" curve shown in Figure 1 is for a single pane construction. Double or triple glazed windows will produce a more complicated version of this curve.

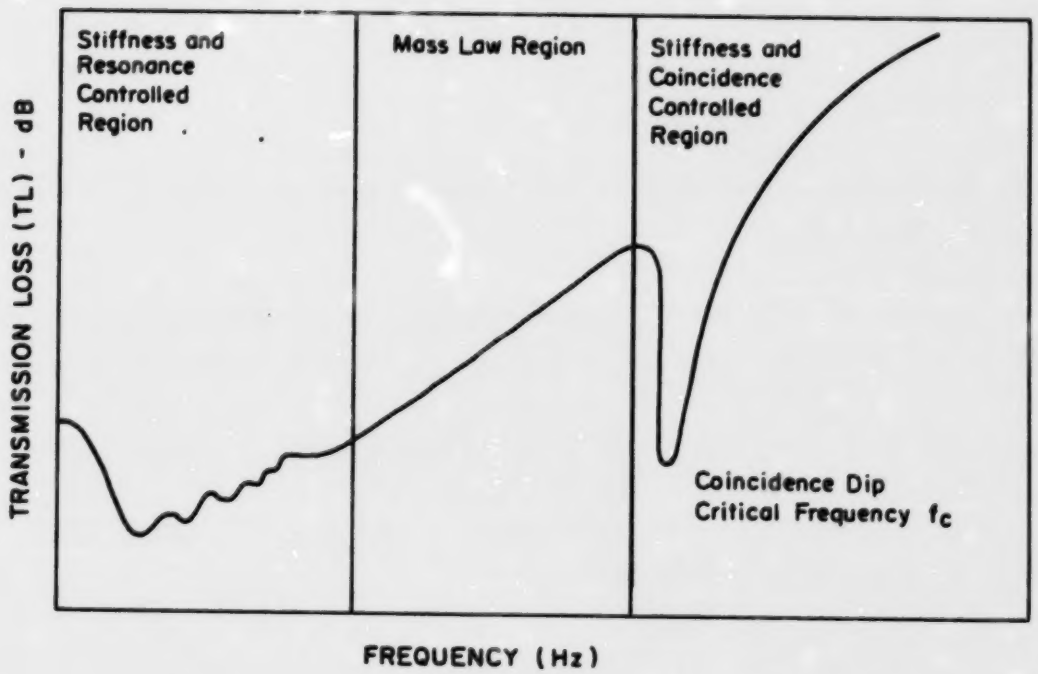


FIGURE 1. TYPICAL TRANSMISSION LOSS OF A WINDOW

Since TL vs frequency curves for complex windows may vary significantly from the standard idealized curve fit used to determine the sound transmission class, sound frequencies of specific interest and their corresponding transmission losses should be determined from graphs in Appendix B to accurately evaluate a sealed unit for a desired use. Some units may have better sound attenuation at higher frequencies, while others may perform better at lower frequencies.

Test Procedure:

Transmission Loss (TL) measurements were made in accordance with:

ASTM E90-81, 'Standard Method of Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.'

Sound Transmission Class (STC) was determined in accordance with:

ASTM E413-73, 'Standard Classification for Determination of Sound Transmission Class.'

2.5 Sample Selection

2.5.1 General Considerations

The units selected for evaluation were combinations of common spacing sizes, seal type and interpane gas fill used in the industry today. The schedule containing the numbers of each type of unit selected for each of the different tests is shown in Table I, page 11.

TABLE I

Sealed Unit Testing Schedule

Type of Sealed Unit	Number of Units Evaluated for Each Performance Category		
	Thermal Performance (760mm x 760mm Samples)	Sound Attenuation (760mm x 760mm Samples)	Seal Durability (350mm x 580mm Samples)
I Single Glazing (5mm)	1 single glazed	1 single glazed	-
II Polyisobutylene Single Seal	1 double glazed 12.7mm spacing	-	-
	1 triple glazed 12.7/12.7mm spacing	-	-
III Polysulphide Single Seal	1 double glazed 6.35mm spacing	-	-
	1 double glazed 12.7mm spacing	1 double glazed 12.7mm spacing	-
	1 triple glazed 6.35/6.35mm spacing	-	-
	1 triple glazed 12.7/12.7mm spacing	1 triple glazed 12.7/12.7mm spacing	-
IV Dual Seal (Polysulphide/ Polyisobutylene)	1 double glazed 6.35mm spacing	-	-
	1 double glazed* 6.35mm spacing	1 double glazed* 6.35mm spacing	-
	1 double glazed 12.7mm spacing	1 double glazed 12.7mm spacing	-
	1 double glazed* 12.7mm spacing	1 double glazed* 12.7mm spacing	18 double glazed* 12.7mm spacing
	1 triple glazed 6.35/6.35mm spacing	-	-
	1 triple glazed* 6.35/6.35mm spacing	1 triple glazed* 6.35/6.35mm spacing	18 triple glazed* 6.35/6.35mm spacing
	1 triple glazed 12.7/12.7mm spacing	1 triple glazed 12.7/12.7mm spacing	-
	1 triple glazed* 12.7/12.7mm spacing	1 triple glazed* 12.7/12.7mm spacing	-
Total Number of Sample Units Tested	15	9	36

* Denotes gas filled with a mixture of Argon and SF6

It is recognized that there are alternative edge seal designs or materials that have been, or currently are used that were excluded from this study. These include fused glass edges, silicone sealants and polyurethane sealants. These were not examined due to the relatively small segment of the market represented, and the fact that some, such as the polyurethane sealants are not yet readily available, and others, such as fused glass are generally experiencing a decline in usage.

All sample units were machine produced under standard shop conditions, being interspersed with regular line production to ensure that they are truly representative of standard commercially fabricated sealed insulating glass units.

Variables considered in this program were:

- sealant type and number of seals;
- number of glazings;
- presence of interpane gas fill; and
- distance between glazings in multiple glazed units.

These variables are discussed in more detail in the following sections.

2.5.2 Edge Seal and Spacer Detail

The seal alternatives examined were; polysulphide with aluminum spacer (single seal); polyisobutylene with aluminum spacer (single seal); and polysulphide/polyisobutylene with aluminum spacer (dual seal). All units contain a 60/40 desiccant mixture of 3 Angstrom molecular sieve/silica gel respectively to remove moisture from the interpane space[6]. The desiccant is installed in 2 legs of the hollow perforated spacer, and is designed to remove up to 300% of dew-point moisture available in the given volume of

interpane space. This allows moisture to be removed from the interpane gas during fabrication, and still leave sufficient desiccant capacity to adsorb additional amounts of moisture that may result from microscopic seal leaks, or moisture vapour transmission through the sealant material. Installation of desiccant amounts in excess of this can increase the possibility of implosion of the sealed units, due to the tendency for some desiccant mixtures to selectively adsorb nitrogen as well as water molecules. Some desiccants may also be designed to selectively evacuate the interpane area of volatile solvents emitted by polysulphides and butyls used as sealant materials.

Polysulphides and polyisobutylenes (hot melt butyls) have been used extensively for sealing insulating glass units since it was recognized that to perform satisfactorily, the edge seal must accommodate differential movement between the glazings and/or glazing/spacer components. The original glass fused edge seal systems, due to the inflexibility of the material, tended to cause stress build-up within the glass itself leading ultimately to failure of the sealed unit. Polysulphides tend to adapt to glazing movements and exhibit rebound characteristics superior to the polyisobutylenes. However, butyls have better water vapour transmission characteristics than the polysulphides, and hence the dual seal system is an attempt to utilize the best properties of both materials in an edge seal system.

The polysulphide materials used in the sample test units were a two component system. The polyisobutylene sealant was applied to the spacer prior to assembly by heated ram type extrusion[6].

2.5.3 Number of Glazings

Standard practice in window construction to improve thermal performance has been to increase the number of glazings used in a sealed window unit. However, although this does reduce the heat losses due to infra-red re-radiation and to some extent conduction/convection from interior spaces, additional glazings are costly to install, can significantly reduce the light transmissivity of the overall unit, and exert an increased loading on the structural components of the window frame. The thermal, durability and sound attenuation characteristics of single, double and triple glazings were evaluated during this program to allow comparative assessment of the performance of multiple glazings.

2.5.4 Interpane Gas Fill

Thermal performance of sealed glazing units can be improved by replacing the interpane air by a gas with a lower thermal conductivity. Gases that are used for this purpose must:

- have a low toxicity
- be stable against ultra-violet rays
- be temperature resistant
- be chemically inert with respect to the materials used in insulating glass manufacture
- not permeate through the edge seal
- have a low dew point
- be reasonably priced

As the width of the inter-glazing space increases, convection becomes increasingly important, and it becomes necessary to use the proper mix between light gases (which are less susceptible to convection movement) and gases which have a lower thermal conductivity[7]. The proper mixture of inert gases can also reduce the transmission of sound energy through the window system.

As is common in industry practice this program used a gas mixture of 70% Argon/30% SF6 for thermal and seal durability test units and 20% Argon/80% SF6 for sound testing units[6].

2.5.5 Distance Between Glazings

In an insulated glass unit, heat is transferred by conductance, convection and radiation. The degree of conductance and convection occurring is governed by the distance between glazings, with either air or gas fill. Convection, or thermally induced movement of air, begins to dominate as the interpane distance increases beyond a certain critical point thereby offsetting the lower conductance benefits achieved through a wider insulating air space. This overriding of conduction loss decreases by convection loss increases generally occurs in interpane spaces >16mm, depending upon certain characteristics of the components in and around the air space such as temperature gradient, gas viscosity, and surface parameters of the glass.

3. TEST RESULTS

3.1 Thermal Performance

The results of the thermal performance measurements are presented in Table II page 18, and were obtained under the test conditions outlined in section 2.2. Average steady state test results are included in Appendix A pages A7 - A21. Since the glazing surfaces of the sample units are not isothermal (not the same temperature at all locations), the surface film coefficients should be considered as approximate.

3.2 Sound Attenuation

The results of the sound tests (STC number) are presented in Table III page 19. A higher STC number indicates a higher Transmission Loss (TL) on the average over the frequency range tested, and therefore a better resistance to sound transmission.

The graphs of measured TL (dB) versus frequency (Hz) are included in Appendix B, Figures B1 to B9, for each sealed unit tested.

3.3 Seal Durability

The results of the seal testing conducted by the National Research Council are included in Appendix C. Two tests were conducted, each consisting of 18 identical samples. The first test evaluated double glazed, 12.7 mm interpane space units, and the second test was carried out on triple glazed units with 6.35 mm interpane spaces. Both sets of samples were of dual seal construction with an argon/SF6 gas fill.

The purpose of this part of the program was to assess the comparative seal performance of double and triple glazed units, representative of the configurations (i.e. dual sealed, multiple glazed) that would most likely be encountered in practice. The integrity of these seals is felt to be extremely important because it represents the only guarantee of retention of premium cost insulating gas. The presence of this gas is not detectable by the consumer.

These test results are discussed in detail in section 4, 'Discussion of Results'.

TABLE II

Thermal Performance - Data Summary Sheet

Sample Description	*Seal Type	Interpane Spacings (mm)	Gas Fill	Average Cold Air Temperature (^{o}C)	Average Warm Air Temperature (^{o}C)	**ΔT (^{o}C)	Cold Surface Film Coefficient ($W/m^2.K$)	Warm Surface Film Coefficient ($W/m^2.K$)	Heat Flux (watts)	***Apparent R_T ($m^2.K/W$)
Triple Glazed	Dual	12.7/12.7	yes	-31.61	+21.94	53.55	12.11	9.40	54.810	0.567
Triple Glazed	Polyisobutylene single	12.7/12.7	no	-33.69	+21.78	55.47	12.15	9.04	57.341	0.562
Triple Glazed	Dual	12.7/12.7	no	-33.84	+21.87	55.71	9.11	9.53	59.607	0.543
Triple Glazed	Dual	6.35/6.35	yes	-33.94	+21.86	55.80	7.68	9.19	61.261	0.529
Triple Glazed	Polysulphide single	12.7/12.7	no	-33.89	+21.75	55.64	33.84	8.90	66.953	0.482
Triple Glazed	Dual	6.35/6.35	no	-34.39	+21.22	55.62	11.01	9.15	69.669	0.463
Triple Glazed	Polysulphide single	6.35/6.35	no	-33.53	+21.64	55.17	16.51	9.13	79.701	0.402
Double Glazed	Polyisobutylene single	12.7	no	-34.07	+21.56	55.63	7.39	10.27	79.858	0.405
Double Glazed	Polysulphide single	12.7	no	-33.99	+21.24	55.23	12.00	8.95	81.844	0.392
Double Glazed	Dual	12.7	yes	-33.84	+21.29	55.13	13.56	10.24	84.153	0.380
Double Glazed	Dual	6.35	yes	-32.79	+22.01	55.00	13.44	8.84	84.348	0.378
Double Glazed	Dual	12.7	no	-33.38	+21.37	53.75	15.30	9.48	87.073	0.365
Double Glazed	Dual	6.35	no	-33.88	+21.51	55.39	10.74	10.77	91.560	0.351
Double Glazed	Polysulphide single	6.35	no	-33.53	+21.26	54.79	19.80	9.31	107.285	0.297
Single Glazing 5mm	-	-	-	-33.99	+21.02	55.00	34.33	19.23	290.010	0.110

* Dual refers to a double polysulphide/polyisobutylene seal.

** ΔT refers to the difference in temperature between the warm side air and the cold side air, measured approximately 100mm from the sample surface.

*** Apparent R_T represents the comparative thermal resistance of the total sample, including warm and cold side air layers under conditions as noted.

TABLE III

Comparison of Sound Attenuation of Sealed Insulating Units

Type of Sealed Unit	No. of Glazings	Spacing of Glazings (mm)	Gas Fill (yes/no)	Test Results (STC number)
I Single Glazing (5 mm) glass	single	-	no	31
II Polysulphide Single Seal	double	12.7	no	33
	triple	12.7/12.7	no	33
III Dual Seal Polysulphide/ Polyisobutylene	double	6.35	yes	30
	double	12.7	no	33
	double	12.7	yes	33
	triple	6.35/6.35	yes	33
	triple	12.7/12.7	no	34
	triple	12.7/12.7	yes	36

The Sound Transmission Classes (STC) are based on generalized curve fitting techniques, and reflect the average performance of the sample. Graphs of the actual Transmission Losses(TL) measured at various frequency levels are included in Appendix B, and should be consulted to assess the performance of a sample for specific sound frequency ranges.

4. DISCUSSION OF RESULTS

4.1 Thermal Performance

It was not possible within the constraints of this program, to exhaustively evaluate using multiple samples, the thermal performance of all possible combinations of seal type, number of glazings, spacing between glazings and gas fill. It must be kept in mind that these measurements are presented as being illustrative of the performance range of each of the sealed units tested, rather than as definitive product performance values. From the simplified matrix of samples tested, the relative importance of each parameter is indicated.

The degree of heat flow reduction through glazings attained by changing the edge seal, adding additional glazings, increasing the interpane spacings, or installing an insulating gas between panes is shown in Table IV, page 21. The samples have been arranged in order of decreasing thermal resistance (apparent R_T) or increasing heat flow, with the least conductive (triple glazed, gas filled, 12.7mm air space, dual seal) unit at the top.

As was expected, the double and triple glazed units exhibited improved thermal performance over a single glazing as the number of glazings, and to a certain degree the interpane spacings, increased. For example,

- The degree of improvement (heat flow reduction) attained by adding a second glazing incorporating a 6.35mm airspace (i.e. double glazing) was between 63.0 and 68.5%, (Table IV, pg 21) depending upon the type of edge seal.

TABLE IV

Percentage Measured Heat Flow Reduction Over a Single Glazed Sample

Sample Description	Seal Type	Interpane Spacings (mm)	Gas Fill	*Heat Flow (watts)	% Reduction in Heat Flow Over Single Glazing	** Apparent R_T (m^2.K/W)
Triple Glazed	Dual	12.7/12.7	yes	54.810	81.10	0.567
Triple Glazed	Polyiso-butylene single	12.7/12.7	no	57.341	80.23	0.562
Triple Glazed	Dual	12.7/12.7	no	59.607	79.45	0.543
Triple Glazed	Dual	6.35/6.35	yes	61.261	78.88	0.529
Triple Glazed	Polysul-phide single	12.7/12.7	no	66.953	76.91	0.482
Triple Glazed	Dual	6.35/6.35	no	69.669	75.98	0.463
Triple Glazed	Polysul-phide single	6.35/6.35	no	79.701	72.52	0.402
Double Glazed	Polyiso-butylene single	12.7	no	79.858	72.46	0.405
Double Glazed	Polysul-phide single	12.7	no	81.844	71.78	0.392
Double Glazed	Dual	12.7	yes	84.153	70.98	0.380
Double Glazed	Dual	6.35	yes	84.348	70.92	0.378
Double Glazed	Dual	12.7	no	87.073	69.98	0.365
Double Glazed	Dual	6.35	no	91.560	68.43	0.351
Double Glazed	Polysul-phide single	6.35	no	107.285	63.01	0.297
Single Glazing	-	5mm glass	-	290.010	-	0.110

* Denotes increasing values of heat flow

** Denotes decreasing values of R_T

- The improvement was between 70.0 and 72.5%, when a second glazing with a 12.7mm airspace was added.

- When two additional glazings were added to the single glazing (triple glazing) incorporating 6.35mm spacings, the heat flow over single glazing was reduced by between 72.5 and 76.0%.

- Two additional glazings with 12.7mm spacings resulted in a 76.9 - 80.2% reduction of heat flow as compared to the single glazed sample. As the spacing increases beyond approximately 16 mm, (depending upon the interpane gas, glass surface characteristics and temperature differentials), the rate of decrease in heat flow may be expected to level out due to the appearance of convective heat transmission. Conditions within the unit are described as changing from a 'conduction' regime at one spacing where heat loss is mainly by conductance, into a 'transition regime' where heat loss is by both conductive and convective mechanisms.[1] To obtain advantages from inceasing the airspace beyond this point would require control of the convective movements within the airspace.

Results indicate that while the initial reduction in heat flow obtained by double glazing over single glazing is substantial, subsequent benefits obtained by triple glazing over double glazing are diminished. For example:

- When a third glazing is added to a double glazed sealed unit with a 6.35mm airspace, the heat flow is reduced by between 23.9 and 25.7%, depending upon the seal type.

- When a third glazing is added to a sealed unit with a 12.7mm airspace, the heat flow is reduced by between 18.2 to 31.5% depending upon the seal type.

- The heat flow reduction obtained by adding a third glazing to a double glazed unit (both gas and non-gas filled) is approximately 50% or less of the benefit derived by the addition of the initial second glazing to the single glazing. This is possibly due to the inherently high conductance of the edge seal system, whose influence increases as the insulating capabilities of the glazing system improve. The effect of these edge losses ultimately will override further potential benefits that may be obtained by adding additional glazings, with or without gas fill.

The rate of heat flow through the sample was influenced by the type of edge seal, with the polyisobutylene single sealed unit consistently showing better insulating characteristics than the dual sealed units. The dual seal units in turn had a lower rate of heat flow than the polysulphide single seal in all but the double glazed 12.7mm space sample. (This exception may be the result of test anomalies such as a more effective surface film on the polysulphide test sample, or loss of seal integrity within the 12.7 mm dual seal unit). It was concluded that the geometry of the polyisobutylene seal, where the glass is separated from the metal spacer by a ribbon of sealant, causes this improved thermal performance by providing a thermal break. Conversely, the polysulphide single seal does not include a separation between glass and spacer, resulting in a thermal bridge at that point. The dual seal units' performance falls between these two extremes.

It is also of interest to compare the benefits of gas filled units with non-gas filled samples having equal numbers of glazings and sizes of airspace.

- Gas filling of the interpane spaces of dual seal units, reduced the heat flow (over non-gas filled units) by 7.9% for the double glazed sample with a 6.35mm spacing and 3.3% for a double glazed sample with 12.7mm spacing.

- The corresponding reductions for triple glazed samples were 12.1% for 6.35mm spacings and 8.0% for the 12.7mm spacings.

- The rate of reduction in heat flow of gas filled units also decreases as the airspace size increases beyond a critical point. As in air filled units, this is due to the appearance of convection heat losses at this point. For this program, gas fill was installed only in samples with dual seals as this is the configuration that would be most common in actual practice.

Factors Affecting the Accuracy of Thermal Test Results

Some anomalies may be present in the thermal data outlined in Tables II, pg. 18 and IV, pg.21, due to possible sample inconsistencies and as a result of overall program constraints. Although the magnitude of these anomalies cannot be accurately determined, a brief discussion will provide an estimate of their effect.

A factor with significant potential for error was the lack of replicate testing carried out on the window units. This resulted in inadequate assessment of the variability of test results and sample units.

Additional sources involve those inherent to the equipment and experimental set up. Although this was not considered to contribute substantially to variations in the test results, it should be noted that the reported accuracy of the type of apparatus used is typically between $\pm$ 1 - 5%.

4.2 Sound Attenuation

Sound testing of the samples showed the poorest performer, other than the single 5mm glazing, to be a double glazed 6.35mm spacing gas filled unit. Examination of the TL vs. Frequency plots in Appendix B indicates that the double glazed 6.35mm spacing unit had slightly lower transmission loss readings at the lower (600 Hz) frequencies, but higher TL readings at the upper frequencies. However, standard STC curve fitting procedures dictate the placing of the curve as shown, giving a higher STC number to the single pane even though there appears to be a much higher degree of sound transmission loss for the double glazed unit for all frequencies above 600 Hz. The STC rating of each curve relates to the sound transmission loss occurring at a standard frequency of 500 Hz, and best fits the performance of a homogeneous solid sample, such as a single glazing, over the full frequency range.

The double glazed 12.7mm spacing units, both with and without gas fill, the triple glazed 6.35/6.35mm spacing unit with gas fill, and the triple glazed 12.7/12.7mm spacing unit polysulphide single seal without gas fill all performed equally well with an STC number of 33. This represents an improvement of 2 sound transmission classes over a single glazing and 3 classes over a double glazed 6.35mm airspace gas filled unit. The triple glazed 12.7mm airspace dual seal unit showed an increase of 3 classes over single glazing, and the sample exhibiting the best performance was the triple glazed 12.7/12.7mm dual seal gas filled unit with a STC number of 36, an improvement of 5 sound transmission classes over single glazing performance.

In summary, it appears that a double glazed 6.35mm sealed unit and single glazing have comparably low sound attenuations, the majority of other samples tested have better sound attenuation

properties by between 2 to 3 classes, and the triple glazed 12.7/12.7 mm airspace gas filled unit achieves a 5 class improvement over single glazing. While gas filling of the triple glazed 12.7 mm dual seal sample increased its STC rating over the non-gas filled triple glazed sample, there was no appreciable benefit measured by adding gas to the double-glazed 12.7 mm sample. It is very important to examine the individual TL vs frequency loss graphs of each sample to assess its sound transmission loss for specific sound frequencies of interest (Appendix B).

4.3 Seal Durability

Testing was conducted on a set of samples comprising 18 double glazed 12.7 mm airspace units and 18 triple glazed 6.35 mm airspace units. Both sets were gas filled and dual sealed. The test results (Appendix C) indicate that,

- the double glazed samples were able to meet the dewpoint temperature requirements of CAN2 12.8 after exposure to all test conditions and,

- some of the triple glazed units, while satisfactorily meeting initial seal test, dew point and ultraviolet fogging requirements, did not exhibit a low enough dew point after high humidity and weather cycling to meet test specifications.

Dew point temperatures were recorded above the specification requirement of $-40^{o}C$ by several of the triple glazed samples. This would indicate that the stresses being applied to edge seal systems increase in direct proportion to the number of glazings present. It would therefore seem prudent for the consumer to take the number of glazings into account when assessing the overall benefits of additional glazings, especially when adding gas

fill to hermetically sealed units as the integrity of the seal is imperative in guaranteeing that insulating gas, once installed, will remain effective. This, of course, also applies to non-gas filled samples that rely on seal integrity to prevent moisture contamination of the insulating air space.

4.4 Additional Observations

4.4.1 During thermal testing, deflection of the surface glazings at midpoint were measured on the cold surface of some units. For example,

- A deflection reducing the interpane distance by approximately 1.52mm on each surface was measured on the triple glazed 6.35/6.35mm gas filled unit and the 12.7mm double and triple glazed units.

- The deflections measured were concave in nature and may have exerted stresses on the glazing and seal components. The reduction of airspace width may also have reduced the thermal resistance of some units.

- Other deflections of 0.76mm, 0.89mm and 2.03mm were measured on double glazed dual seal 12.7mm spacing, 6.35mm spacing and 12.7mm spacing triple glazed polysulphide single seal units respectively.

Interestingly, on the two polyisobutylene single seal samples checked (12.7/12.7mm triple glazed and 12.7mm double glazed), no deflections were apparent. This may be due to the characteristically poor adhesion of the butyls at low temperatures resulting in spacer movement which allowed pressure build ups to dissipate. However, it was not possible to check the integrity of the seal after thermal testing to confirm this.

4.4.2. In order to evaluate the extent of the window area affected by thermal bridging occurring at the edge spacer, temperature profiles were measured near the edges of four of the samples which had been used for heat flow measurements (i.e. 6.35mm double glazed, 12.7mm double glazed, 6.35mm gas filled triple glazed, 12.7mm triple glazed). Areas affected by the higher conductance of the spacers (thermal bridges) ranged from 19 - 30% of the total glazing area.

5. CONCLUSIONS

The sealed window samples have been arranged in descending order of heat flow and sound attenuation (STC) in Summary Table V, pg. 30. Apart from seal durability, which was unsatisfactory for the triple glazed units, the following conclusions can be made.

- The unit that performed the best, both thermally and acoustically, was the triple glazed 12.7mm spacing gas filled unit. The heat flow through this unit decreased 8.0%, and sound attenuation improved by 2 sound transmission classes over an equivalent non-gas filled unit.

Test results indicate a direct relationship between the spacing and/or number of glazings and the thermal and sound attenuation performance in a sealed glass unit.

- The largest incremental reduction in heat flow occurs between single glazing and double glazing (63% reduction from single glazing to 6.35mm airspace double glazing, and 70% reduction from single glazing to 12.7mm airspace double glazing).

- Additional heat flow reductions from further improvements are much smaller for both increased glazings, increased interpane airspace size, and gas filling.

- The heat flow decreased 31.5% by going from double glazed 12.7 mm to triple glazed 12.7 mm spacing (dual seal non gas filled).

TABLE V

Summary of Test Results, With Samples Presented in Order of Increasing Resistance to Thermal and Sound Transmission

Sample Description (see key below)	Thermal Performance			**Sound Transmission	*Seal Durability
	Apparent R_T (m^2.K/W)	Heat Flow (W)	Reduction in Heat Flow Over Single Glazing (%)	(STC Rating)	(CAN2 12.8 Rating)
TGU DS GF 12.7/12.7	0.567	54.810	81.1	36	-
TGU PBSS NGF 12.7/12.7	0.562	57.341	80.2	-	-
TGU DS NGF 12.7/12.7	0.543	59.607	79.5	34	-
TGU DS GF 6.35/6.35	0.529	61.261	78.9	33	unsatisfactory
TGU PSSS NGF 12.7/12.7	0.482	66.953	76.9	33	-
TGU DS NGF 6.35/6.35	0.463	69.669	76.0	-	-
TGU PSSS NGF 6.35/6.35	0.402	79.701	72.5	-	-
DGU PBSS NGF 12.7	0.405	79.858	72.5	-	-
DGU PSSS NGF 12.7	0.392	81.844	71.8	33	-
DGU DS GF 12.7	0.380	84.153	71.0	33	satisfactory
DGU DS GF 6.35	0.378	84.348	71.0	30	-
DGU DS NGF 12.7	0.365	87.073	70.0	33	-
DGU DS NGF 6.35	0.351	91.560	68.4	-	-
DGU PSSS NGF 6.35	0.297	107.285	63.0	-	-
SGU - 5 mm glass	0.110	290.010	-	31	-

KEY:
- TGU - triple glazed unit
- DGU - double glazed unit
- SGU - single glazed unit
- DS - dual seal (polysulphide/polyisobutylene)
- PSSS - polysulphide single seal
- PBSS - polyisobutylene single seal
- GF - gas filled
- NGF - non gas filled

12.7/12.7 - interpane spacings of 12.7mm for a triple glazed unit

12.7 - interpane spacing of 12.7mm for a double glazed unit.

* 2 configurations - double glazed dual seal and triple glazed dual seal (gas filled) were tested. Satisfactory rating means that after testing, all units retain a dew point below -40°C. 18 samples were tested for each configuration.

** 9 configurations were tested and each assigned a Sound Transmission Class rating, as described in section 2.4.

- The heat flow decreased by 24% by going from double glazed 6.35 mm to triple glazed (dual seal non gas filled).

- The sound attenuation increased one STC class by adding a third glazing to a double glazed 12.7 mm unit (dual seal, non-gas filled).

- Equal benefits (2 sound transmission classes) are obtained in reducing sound transmission below that of single glazing by adding a second glazing with a 12.7mm spacing, with or without gas fill or by adding two additional glazings 6.35mm spacings with gas fill.

- Heat flow occurring near the edges of the units appears to be sufficiently large to provide an area where meaningful improvements in thermal performance could be made by using edge spacer systems of lower conductance.

There was an observable trend in thermal performance (heat flow) with the type of edge seal used.

- The polyisobutylene single seal out-performed the dual sealed units by between 3.8% for the triple glazed 12.7 mm spacing and 8.3% for the double glazed 12.7 mm spacing.

- The dual seal in turn performed better than the polysulphide single seal by 11.0% for the triple glazed 12.7 mm, 12.6% for triple glazed 6.35 mm, and 14.7% for double glazed 6.35 mm spacings. (The double glazed 12.7 mm sample did not follow this trend, possibly because of factors discussed in section 4.1.).

- This trend is most likely due to the direct contact that exists between glass and metal spacer in the polysulphide single seal units.

- The polyisobutylene single seal exhibited spacer movement during thermal tests, possibly due to thermally induced pressure differentials which raises questions about the integrity of the seal.

- Concave deflections observed on several samples indicate a performance reduction which is temperature dependent. The degree of thermal or sound performance reduction is governed by the thermal expansion characteristics of the gas fill and seal integrity, while the durability of the edge seal is affected by the number of hot/cold cycles and the subsequent stresses being concentrated at the edge seal.

In conclusion, all the performance data presented in this report was derived from single unit testing, and as such may be subject to errors arising from 'one of a kind' measurements. However, the trends established are valid in so far as they present a range within which the performance of these types of sealed units can be expected to fall, under the test conditions documented. The data also must be evaluated in conjunction with the individual cost of adding each feature to the baseline single glazed window. Only by including initial capital costs of each item can a true picture of the comparative net benefits of a given window system be developed.

BIBLIOGRAPHY

1. Thermal Performance of Insulating Window Systems by Stephen E. Selkowitz, ASHRAE Transactions, Volume 85, 1979, pg 669.

2. 'Factory Sealed Double Glazing Units', by K. R. Solvason and A. G. Wilson, Canadian Building Digest, National Research Council, CBD 46.

3. American Society for Testing and Materials, 'Standard Definitiions of Terms Relating to environmental Accoustics: 'ASTM C634-79 ASTM, 1982, pg 348.

4. Kopel, John W., 'Vibrations in Sound Transmission on Steel Studded Gypsum Walls', in 'Sound and Vibration', June 1982.

5. Beranek, L.L. (ed): 'Noise Reduction', McGraw-Hill, 1960.

6. Manufacturers Information - June 1983.

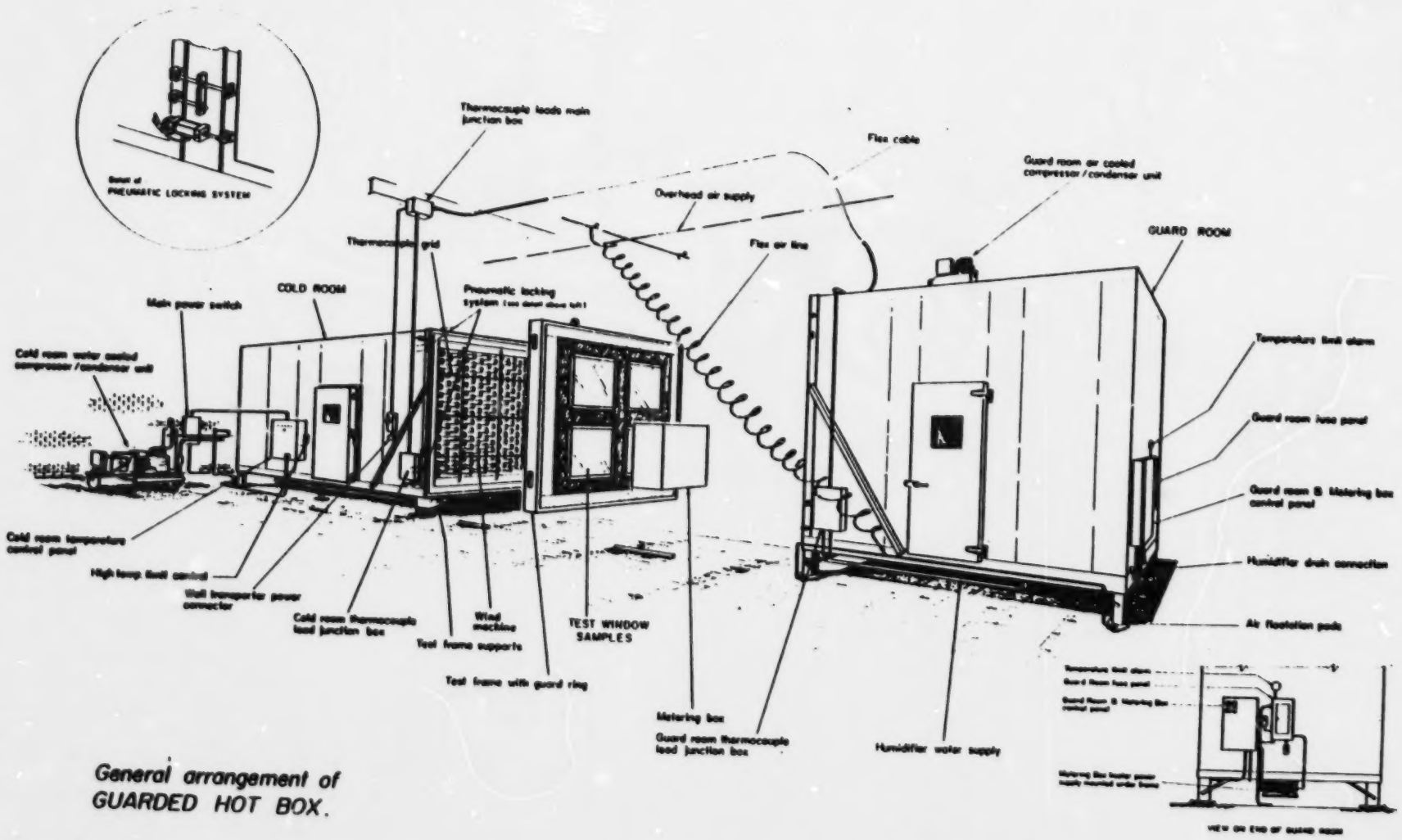
7. 'Gas Filling - a do-it-yourself Method for Producing High Performance Insulating Glass', by Jost Pruessing Pector GMBH INDUSTRIETECHNIK, Munich W. Germany.

8. 'Thermal Characteristics of Double Windows', by A. G. Wilson and W.P. Brown, Canadian Buildng Digest, National Research Council, CBD 58.

9. 'ASHRAE HANDBOOK, 1977 FUNDAMENTALS', published by the American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1978. Section 22.

APPENDIX A

Thermal Testing
Description and Results



General arrangement of GUARDED HOT BOX.

FIGURE A1

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GUARDED HOT BOX RATIONALE AND TEST PROCEDURES

The guarded hot box method determines the thermal properties of a test sample, through the measurement of heat flow under controlled steady-state conditions. The thermal properties are determined in terms of apparent thermal resistance, which may be defined as the temperature difference between two isothermal surfaces when a unit heat flow per unit area is established between the surfaces. This apparent thermal resistance, R, is actually the inverse of thermal conductance, and is calculated:

$$R = (t_1 - t_2)\, A/q \qquad (1)$$

Where t_1 = temperature of the hot surface, (K)

t_2 = temperature of the cold surface, (K)

A = area normal to heat flow, (sq. m.) ie. metered area of the test panel

q = time rate of heat flow-through area A, (W)

In practice, the q in the above equation cannot be measured directly, but can be calculated, based on the total power required by the metering box heater and the heat flow through the metering box walls.

$$q = Q + ME \qquad (2)$$

Where Q = total power required by the metering box heater, (W)

M = metering box constant, (W/mV)

E = thermopile emf, (mV)

Combining equations 1 and 2, R is calculated:

$$R = (t_1 - t_2)\, A/Q + ME \qquad (3)$$

In addition to the apparent R-value, the computer system also calculates the surface film coefficients for the hot and cold surfaces of the test panel. These coefficients, h_h and h_c respectively, are defined as the time rate of heat flow per unit area of a particular surface by the combined effects of radiation, conduction and convection for a unit temperature difference between the surface and the surrounding air. The surface film coefficients are used to indicate the air flow characteristics on the cold and hot sides of the test panel, and are calculated:

$$h_h = (Q + ME)/A(t_h - t_1) \qquad (4)$$

$$h_c = (Q + ME)/A(t_2 - t_c) \qquad (5)$$

Where t_h = air temperature > 75mm from the hot surface, (K)

t_c = air temperature > 75mm from the cold surface, (K)

In the test mode the computer collects temperature and power data from the thermocouple grids and power equipment at predefined interrupt intervals. In between these interrupts the operator can manually scan the grids by using the soft key options.

The data collection and manipulation can be summarized as follows:

Time Interval: 30 seconds

- scans channels in sequence
- converts scan data to appropriate units of temperature or power
- averages the temperature data for each grid
- sums the power data

Time Interval: 5 minutes

- averages all the 30 second data
- displays status on the screen

Time Interval: 30 minutes

- averages the 5 minute averages
- calculates R-values for the 30 minute section
- reports data used in the calculation as well as the calculated values on the printer.

Time Interval: 4 hours

- averages the 30 minute averages
- averages the calculated R-values
- reports the 4 hour R-values on the printer

These steps are repeated to obtain sufficient 4 hour values to complete the required number of continuous hours of testing. At each 4 hour point the R-values are averaged and each 4 hour R-value is compared to the mean. If any of the differences from the mean are greater than 1%, the first 4 hours period data is dropped, therefore, requiring another 4 hours of testing. If, however, the differences from the mean are all less than 1% and the number of continuous hours required has been satisfied, then the test is complete. A summary report is printed.

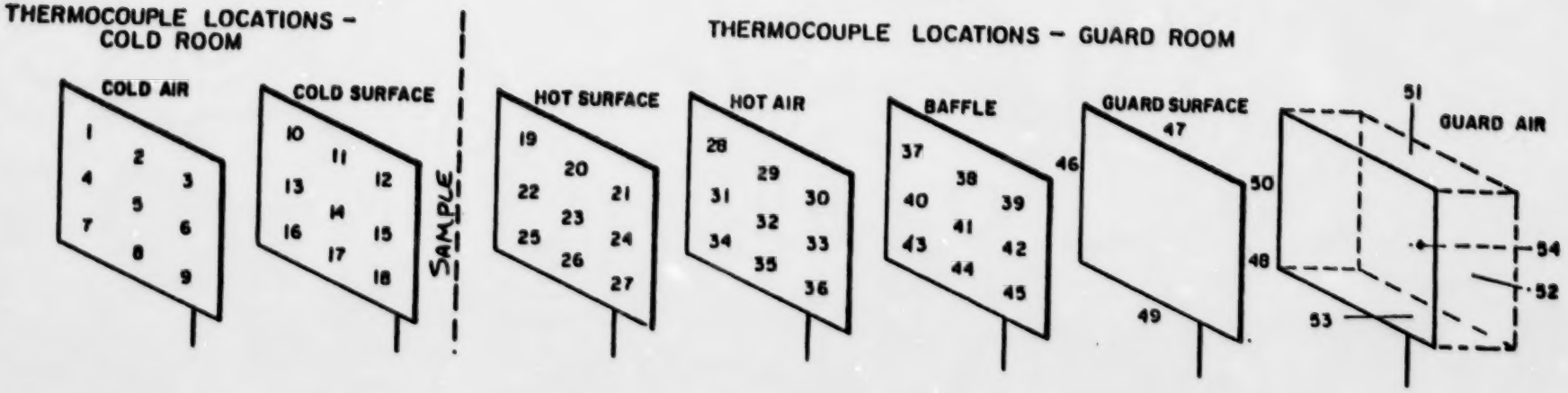
THERMOCOUPLE LOCATIONS

The thermocouples installed on a cold air grid; on the cold side surface of the sample; on the warm side surface of the sample; and on a warm air grid, are monitored to obtain the Grid Temperatures as presented on the following pages. The thermocouples are arranged for all components of the guarded hot box, as shown in Figure 2, with thermocouple location numbers 1 to 36 giving the temperature readings shown in the following sections. The additional thermocouples are used by the computer to automatically adjust temperatures in the guard rooms and precisely control test conditions.

The location of each data point in the grid temperature tables may be determined by reference to the lower portion of Figure 2. Here, a sample grid temperature chart is presented with temperature readings replaced by the thermocouple location numbers.

FIGURE A2

Thermocouple Locations



Sample Grid Temperature Table

Location in Grid Temperature tables correspond to thermocouple locations as shown below.

Grid Temperatures

Cold Air

1	2	3
4	5	6
7	8	9

Cold Surface

10	11	12
13	14	15
16	17	18

Hot Air

19	20	21
22	23	24
25	26	27

Hot Surface

28	29	30
31	32	33
34	35	36

TEST DATA KEY

Test No.	Sample Description
4	Single glass 5mm
5	Double glazed, Dual seal 4mm/6.35/4mm- gas filled
6	Triple galzed, Dual seal 4mm/12.7/12.7/4mm - gas filled
7	Double glazed, Dual seal 4mm/12.7/4mm
8	Double glazed, Polysulphide single seal 4mm/6.35/4mm
9	Triple glazed, Dual seal 4mm/6.35/6.35/4mm
10	Triple glazed, Polysulphide single seal 4mm/6.35/6.35/4mm
11	Triple glazed, Dual seal 4mm/12.7/12.7/4mm
12	Double glazed, Dual seal 4mm/6.35/4mm
13	Triple glazed, Polyisobutylene single seal 4mm/12.7/12.7/4mm
14	Triple glazed, Polysulphide single seal 4mm/12.7/12.7/4mm
15	Double glazed, Polyisobutylene single seal 4mm/12.7/4mm
16	Double glazed, Polysulphide single seal 4mm/12/7/4mm
17	Triple glazed, Dual seal 4mm/6.35/6.35/m44 - gas filled
18	Double glazed, Dual seal 5mm/12.7.3mm - gas filled

Final Summary
Windows II - Single Pane Glass

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-33.94	-19.46	-5.02	+20.99	+.414	+288.337	+.111	+.029
2	-34.03	-19.59	-5.03	+21.04	+.411	+290.755	+.110	+.029
Average	-33.99	-19.53	-5.03	+21.02	+.412	+289.546	+.110	+.029

Surface Film Coefficients

Cold Surface +34.33 Hot Surface +19.23

Final Summary
Windows II - Double Glased Unit Dual Seal 6.35mm g.f.

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-32.72	-21.89	+5.90	+22.17	+.412	+83.355	+.382	+.193
2	-32.80	-22.13	+5.81	+22.25	+.404	+84.113	+.379	+.192
Average	-32.76	-22.01	+5.85	+22.21	+.408	+83.734	+.380	+.193
Imperial Units							2.158	1.096

Surface Film Coefficients

Cold Surface 13.44 Hot Surface 8.84

Final Summary
Windows II - Triple Glazed Unit g.f. 12.7/12.7mm Dual Seal

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-31.59	-23.80	+11.92	+21.94	+.404	+54.445	+.569	+.380
2	-31.63	-23.86	+11.91	+21.94	+.402	+54.633	+.568	+.379
Average	-31.61	-23.83	+11.92	+21.94	+.403	+54.539	+.568	+.379
Imperial Units							3.225	2.152

Surface Film Coefficients

Cold Surface +12.11 Hot Surface +9.40

Final Summary
Windows II - D.G.U. PS/PB Dual Seal 12.7mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_w
1	-33.36	-23.58	+5.57	+21.37	+.202	+86.782	+.366	+.195
2	-33.41	-23.58	+5.54	+21.37	+.202	+87.203	+.364	+.194
Average	-33.38	-23.58	+5.55	+21.37	+.202	+86.993	+.365	+.194
Imperial Units							.207	1.102

Surface Film Coefficients

Cold Surface +15.30 Hot Surface +9.48

Final Summary
Windows II - D.G.U. PS Single Seal 4mm/6.35mm/4mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-33.32	-23.95	+1.57	+21.28	+.200	+106.020	+.299	+.140
2	-33.84	-24.43	+1.27	+21.24	+.205	+108.389	+.294	+.138
Average	-33.53	-24.19	+1.42	+21.26	+.202	+107.205	+.297	+.139
Imperial Units							1.686	0.789

Surface Film Coefficients

Cold Surface +19.80 Hot Surface +9.31

Final Summary
Windows II - T.G.U. PS/PB Dual Seal 6.35mm/6.35mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-34.39	-23.49	+8.11	+21.22	+.203	+69.544	+.464	+.263
2	-34.40	-23.51	+8.10	+21.21	+.207	+69.632	+.463	+.263
Average	-34.39	-23.50	+8.10	+21.22	+.205	+69.588	+.463	+.263

Surface Film Coefficients

Cold Surface +11.01 Hot Surface +9.15

Final Summary
Windows II- T.G.U. PS Single Seal 6.35mm/6.35mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_w
1	-33.43	-25.33	+6.53	+21.65	+.205	+80.017	+.400	+.231
2	-33.64	-25.11	+6.68	+21.63	+.201	+79.225	+.405	+.233
Average	-33.53	-25.22	+6.60	+21.64	+.203	+79.621	+.402	+.232
Imperial Units							2.28	1.32

Surface Film Coefficients

Cold Surface +16.51 Hot Surface +9.13

Final Summary
Windows II - T.G.U. PS/PB Dual Seal 12.7/12.7

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-33.84	-22.60	+11.08	+21.87	+.201	+59.567	+.542	+.328
2	-33.84	-22.55	+11.11	+21.87	+.201	+59.488	+.543	+.328
Average	-33.84	-22.57	+11.09	+21.87	+.201	+59.527	+.543	+.328
Imperial Units							3.084	1.863

Surface Film Coefficients

Cold Surface +9.11 Hot Surface +9.53

Final Summary
Windows II - D.G.U. PS/PB Dual Seal 6.35mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_w
1	-33.88	-19.21	+6.86	+21.51	+.199	+91.662	+.351	+.165
2	-33.89	-19.19	+6.88	+21.52	+.198	+91.299	+.352	+.166
Average	-33.88	-19.20	+6.87	+21.51	+.199	+91.481	+.351	+.165
Imperial Units							1.993	0.937

Surface Film Coefficients

Cold Surface +10.74 Hot Surface +10.77

Final Summary
Windows II - T.G.U. PB Single Seal 12.7mm/12.7mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_w
1	-33.70	-25.57	+10.89	+21.80	+.203	+57.145	+.563	+.370
2	-33.68	-25.55	+10.80	+21.76	+.201	+57.377	+.560	+.367
Average	-33.69	-25.56	+10.85	+21.78	+.202	+57.261	+.562	+.369
Imperial Units							3.191	2.095

Surface Film Coefficients

Cold Surface +12.15 Hot Surface +9.04

Final Summary
Windows II - T.G.U. PS Single Seal 12.7mm/12.7mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-33.89	-30.46	+8.79	+21.74	+.198	+66.690	+.484	+.341
2	-33.89	-30.51	+8.78	+21.75	+.208	+67.055	+.481	+.340
Average	-33.89	-30.48	+8.79	+21.75	+.203	+66.872	+.482	+.341
Imperial Units							2.737	1.93

Surface Film Coefficients

Cold Surface +33.84 Hot Surface +8.90

Final Summary
Windows II - D.G.U. PB Single Seal Opt. Temp. 12.7mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_w
1	-34.05	-15.35	+8.26	+21.59	+.189	+79.106	+.408	+.173
2	-34.09	-15.54	+8.09	+21.53	+.205	+80.455	+.401	+.170
Average	-34.07	-15.45	+8.17	+21.56	+.197	+79.780	+.405	+.172

Surface Film Coefficients

Cold Surface +7.39 Hot Surface +10.27

Final Summary
Windows II - D.G.U. PS Single Seal 12.7mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-33.96	-22.21	+5.49	+21.23	+.191	+81.692	+.392	+.197
2	-34.02	-22.26	+5.48	+21.25	+.192	+81.843	+.392	+.197
Average	-33.99	-22.24	+5.49	+21.24	+.192	+81.768	+.392	+.197
Imperial Units							2.226	1.119

Surface Film Coefficients

Cold Surface +12.00 Hot Surface +8.95

Final Summary
Windows II - T.G.U. PS/PB Dual Seal Gas 6.35/6.35mm opt. Temp.

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-34.01	-20.26	+10.36	+21.84	+.193	+61.155	+.530	+.290
2	-33.89	-20.17	+10.39	+21.86	+.193	+61.266	+.528	+.289
3	-33.95	-20.20	+10.40	+21.88	+.202	+61.218	+.529	+.290
4	-33.93	-20.19	+10.40	+21.89	+.198	+61.152	+.529	+.290
5	-33.90	-20.16	+10.38	+21.86	+.188	+61.131	+.529	+.290
Average	-33.94	-20.20	+10.39	+21.86	+.195	+61.184	+.529	+.290

Surface Film Coefficients

Cold Surface +7.68 Hot Surface +9.19

Final Summary
Windows II - D.G.U. PS/PB Dual Seal Gas 5/12.7/3mm

Period	Cold Air	Cold Surf.	Hot Surf.	Hot Air	E	Q	R_T	R_W
1	-33.84	-23.10	+7.14	+21.29	+.195	+84.160	+.380	+.208
2	-33.84	-23.20	+7.12	+21.28	+.195	+83.992	+.381	+.209
Average	-33.84	-23.15	+7.13	+21.29	+.195	+84.076	+.380	+.209
Imperial Units							2.158	1.187

Surface Film Coefficients

Cold Surface +13.56 Hot Surface +10.24

APPENDIX B

Sound Transmission Tests
Transmission Loss vs. Frequency Plots

FIGURE B1

Unit P

Double Glazed Polysulphide Single Seal 12.7mm Airspace

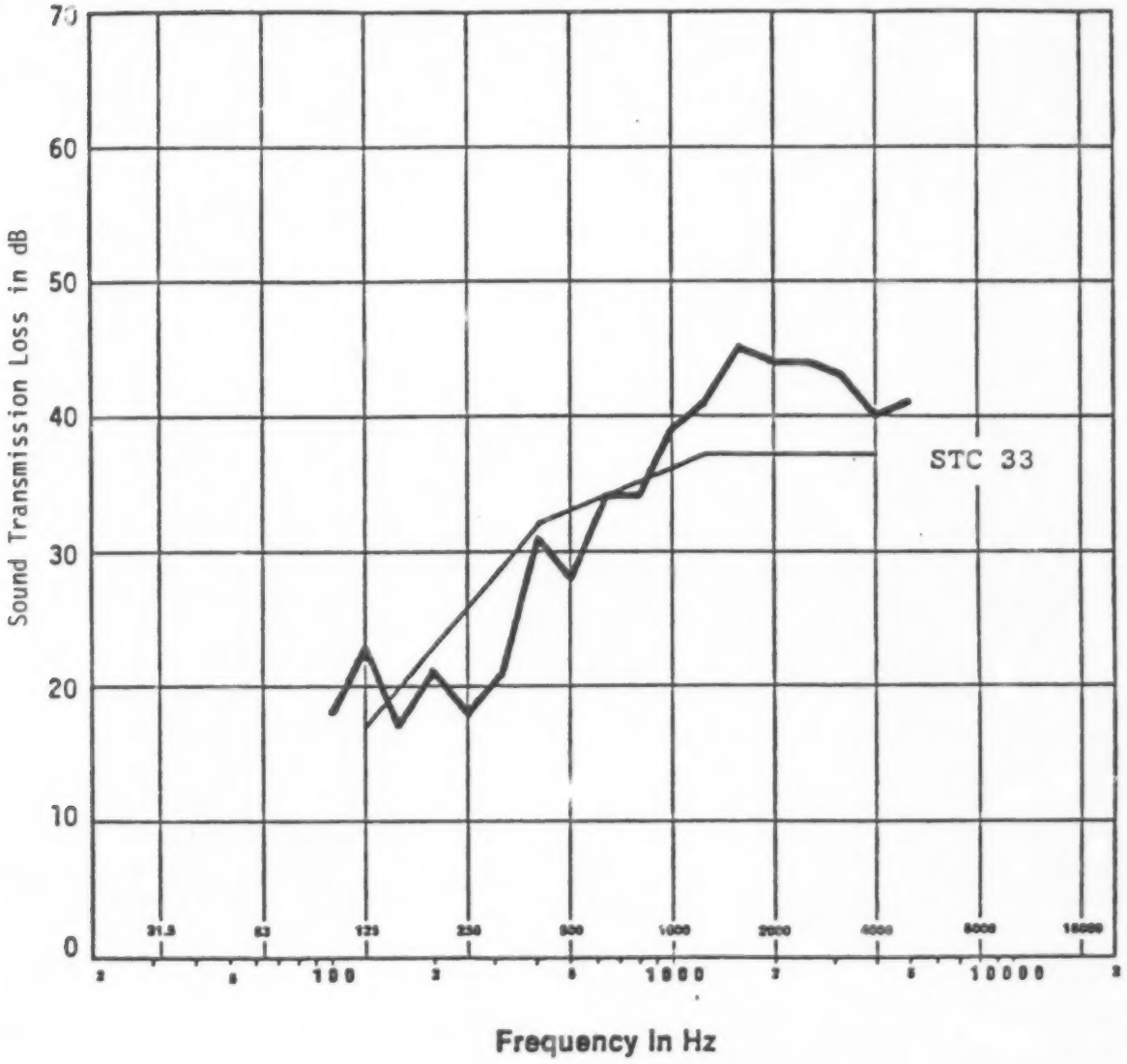


FIGURE B2

Unit Q

Triple Glazed-Polysulphide Single Seal 12.7/12.7mm Airspace

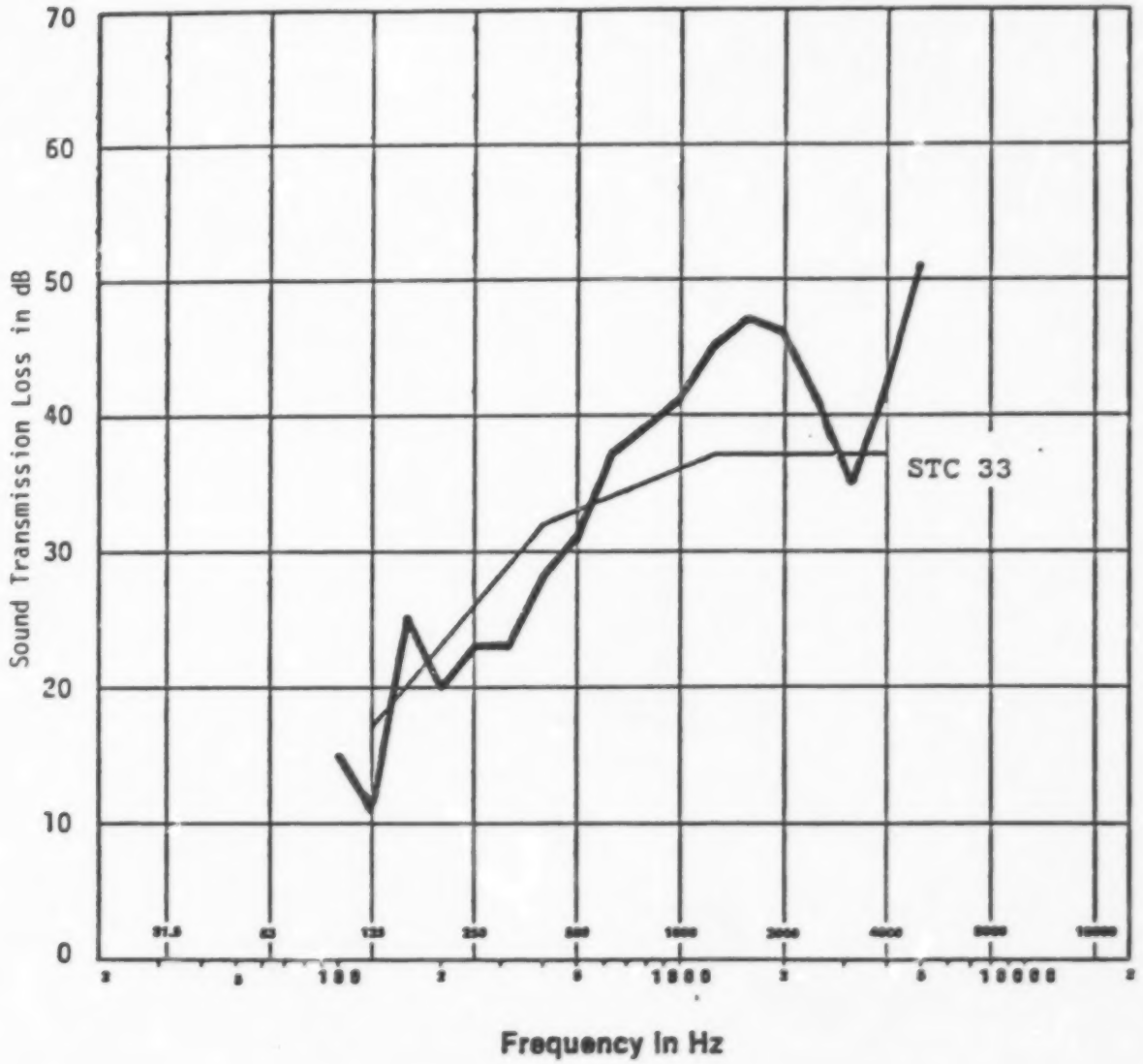


FIGURE B3

Unit S

Triple Glazed Dual Seal 12.7/12.7mm Airspace

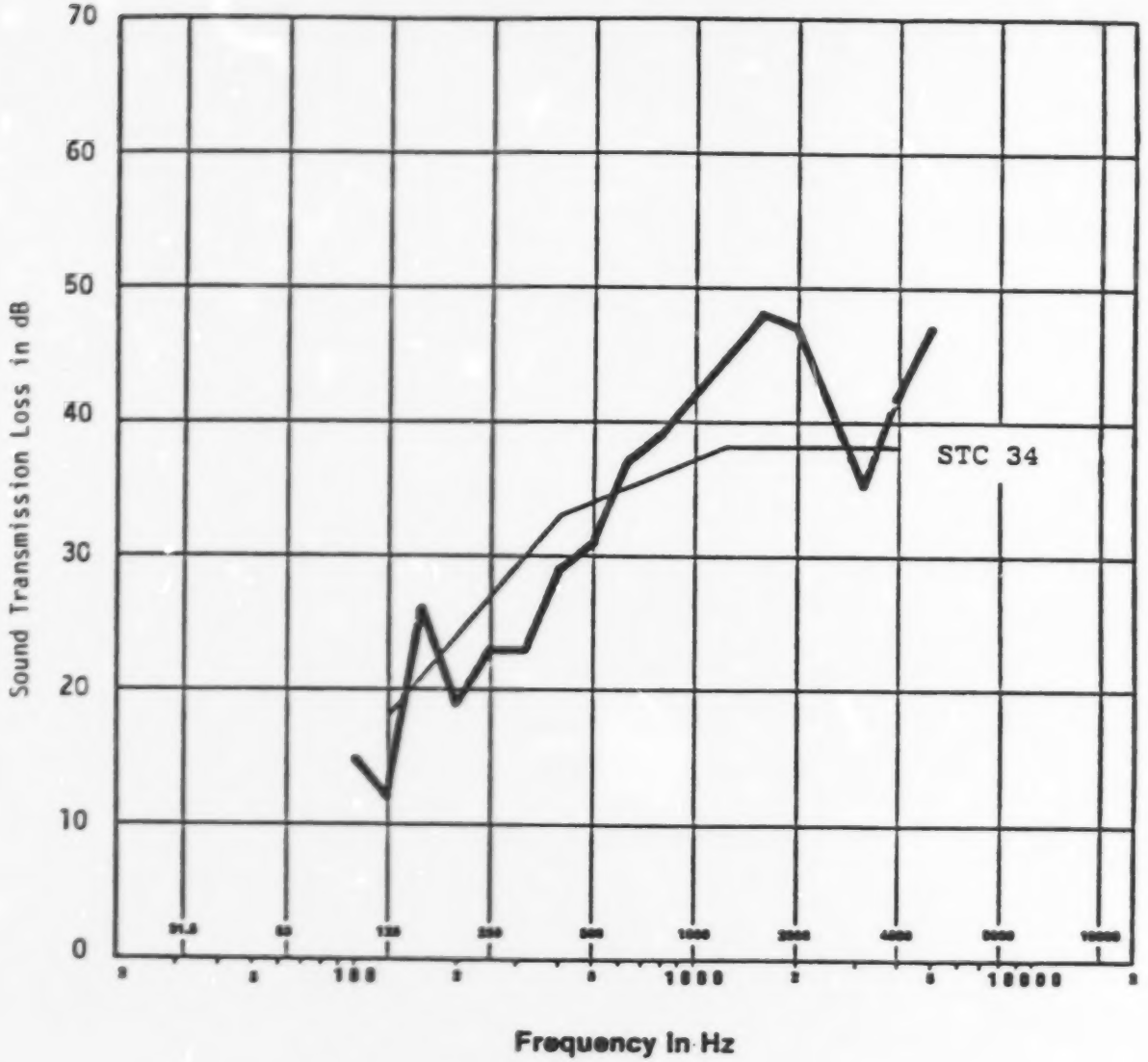


FIGURE B4

Unit T

Double Glazed Dual Seal Gas Filled 12.7mm Airspace

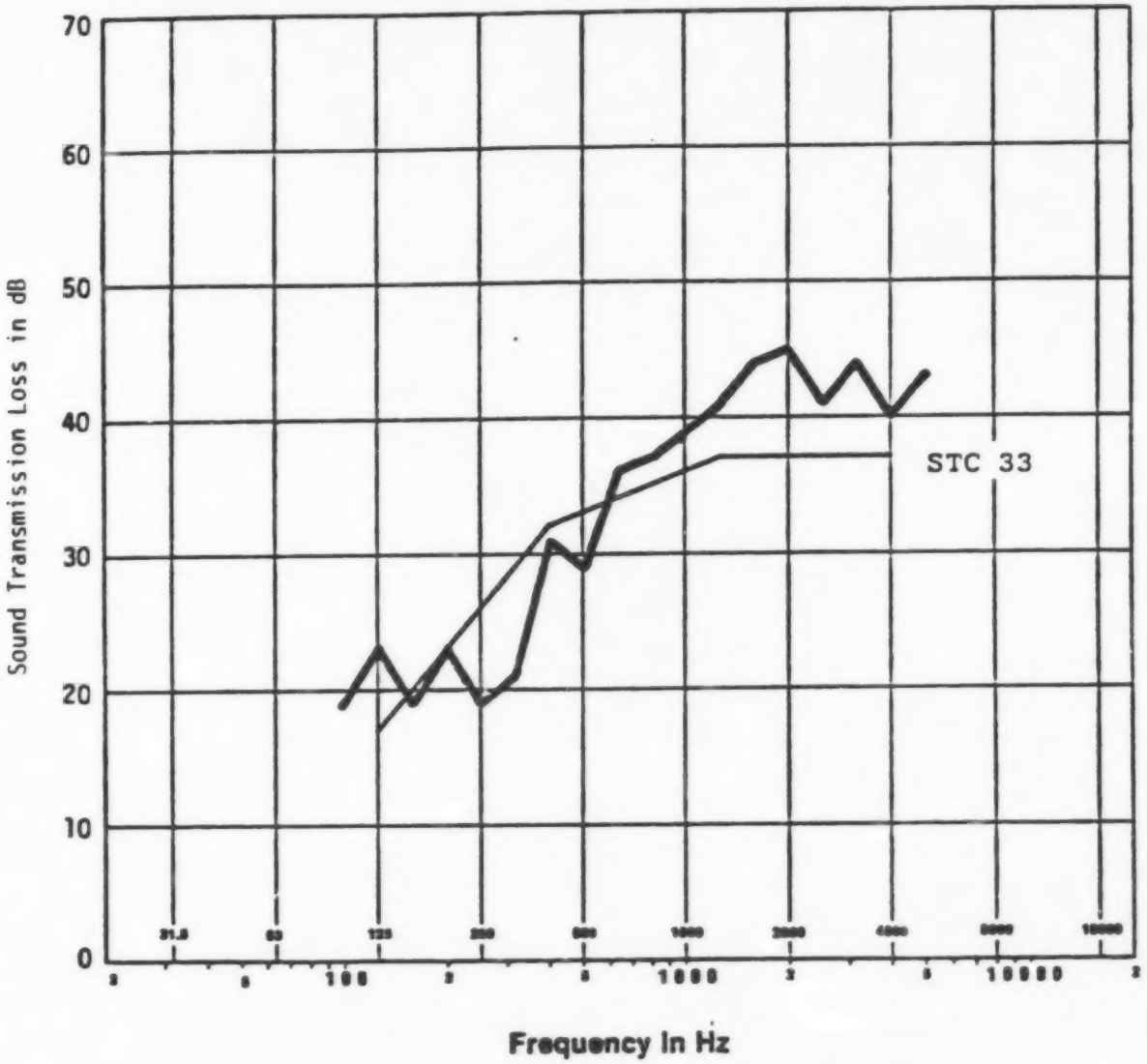


FIGURE B5

Unit U

Double Glazed Dual Seal Gas Filled 6.35mm Airspace

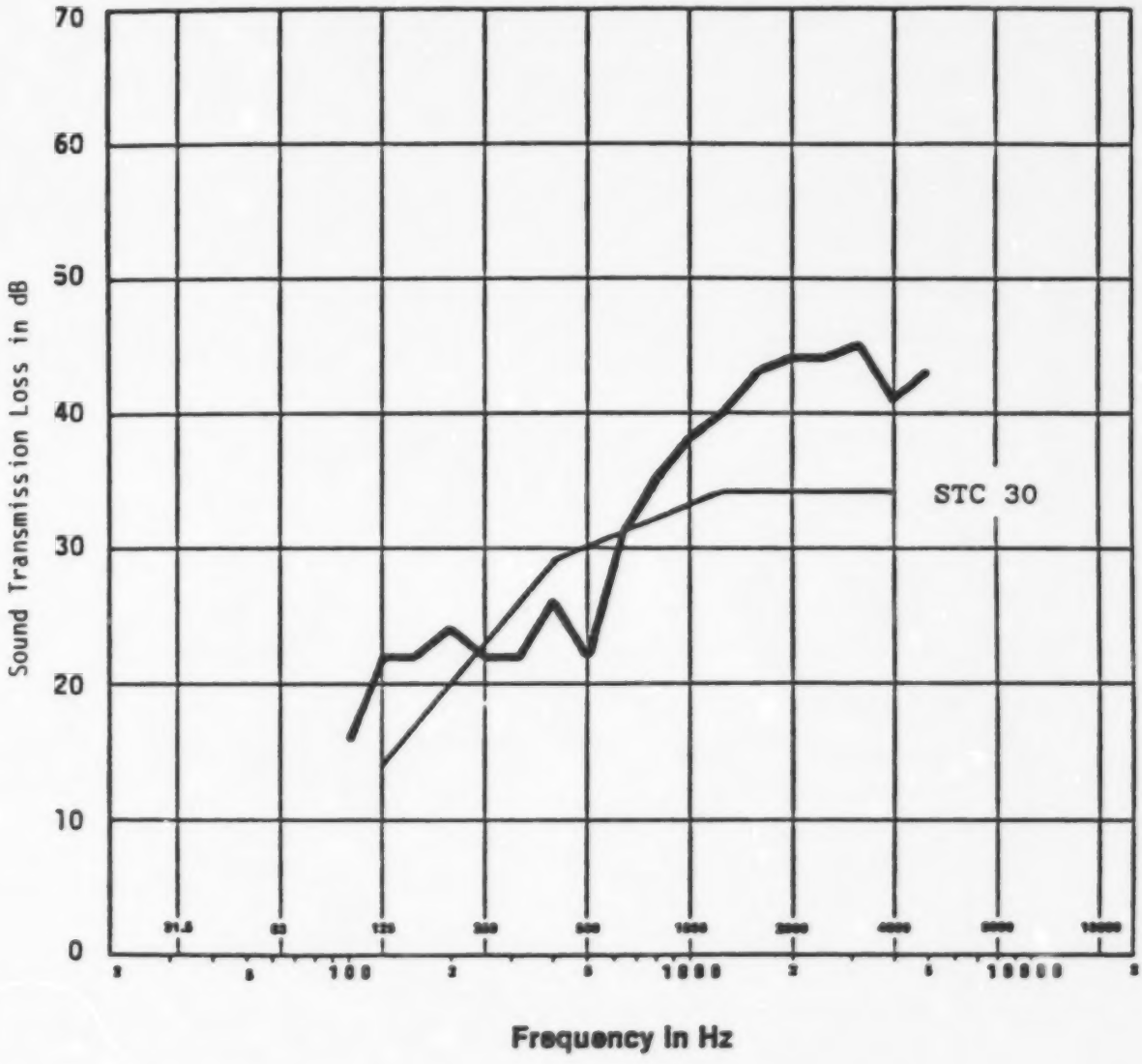


FIGURE B6

Unit V

Triple Glazed Dual Seal Gas filled 12.7/12.7mm Airspace

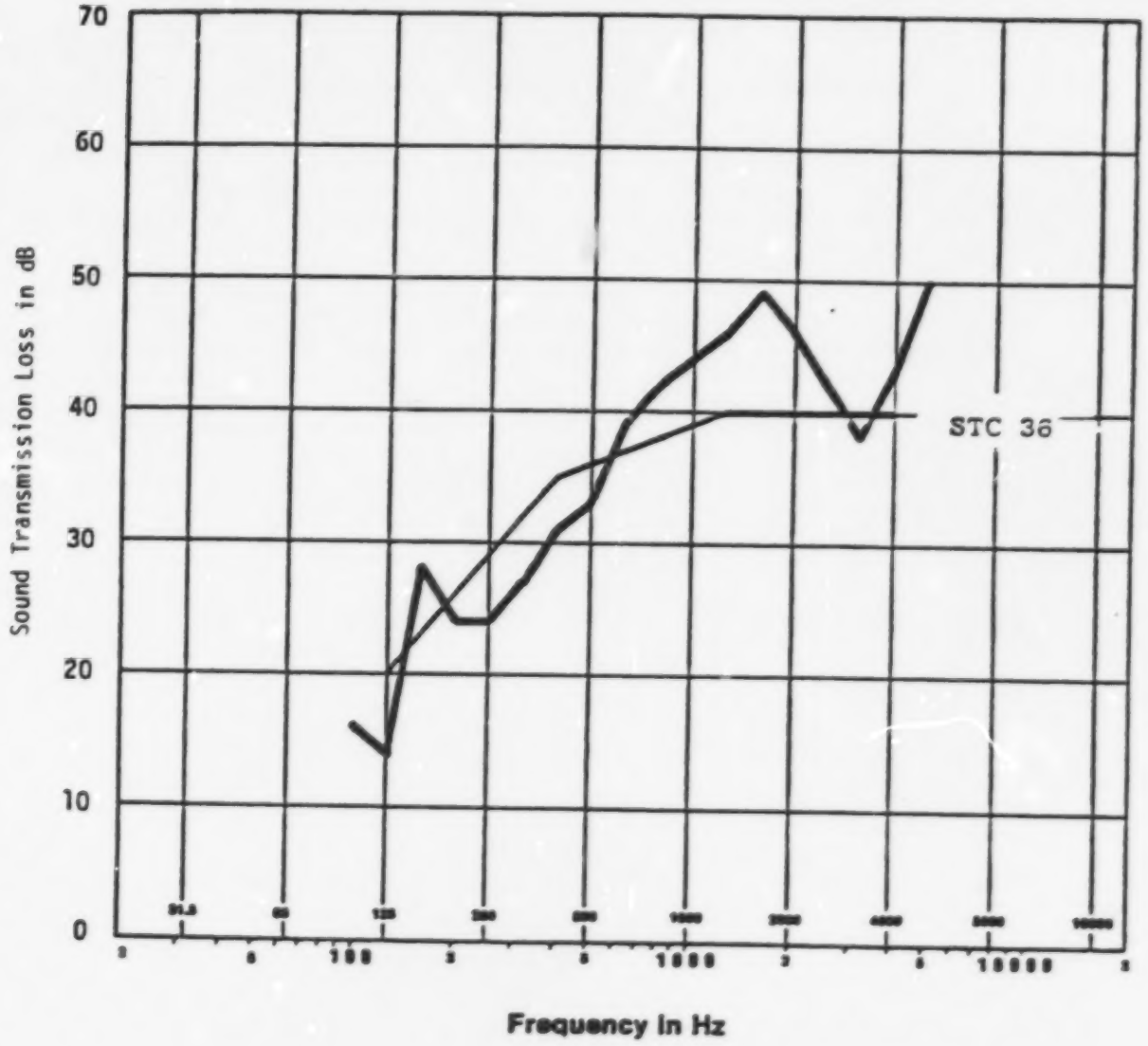


FIGURE B7

Unit W

Triple Glazed Dual Seal Gas Filled 6.35/6.35mm Airspace

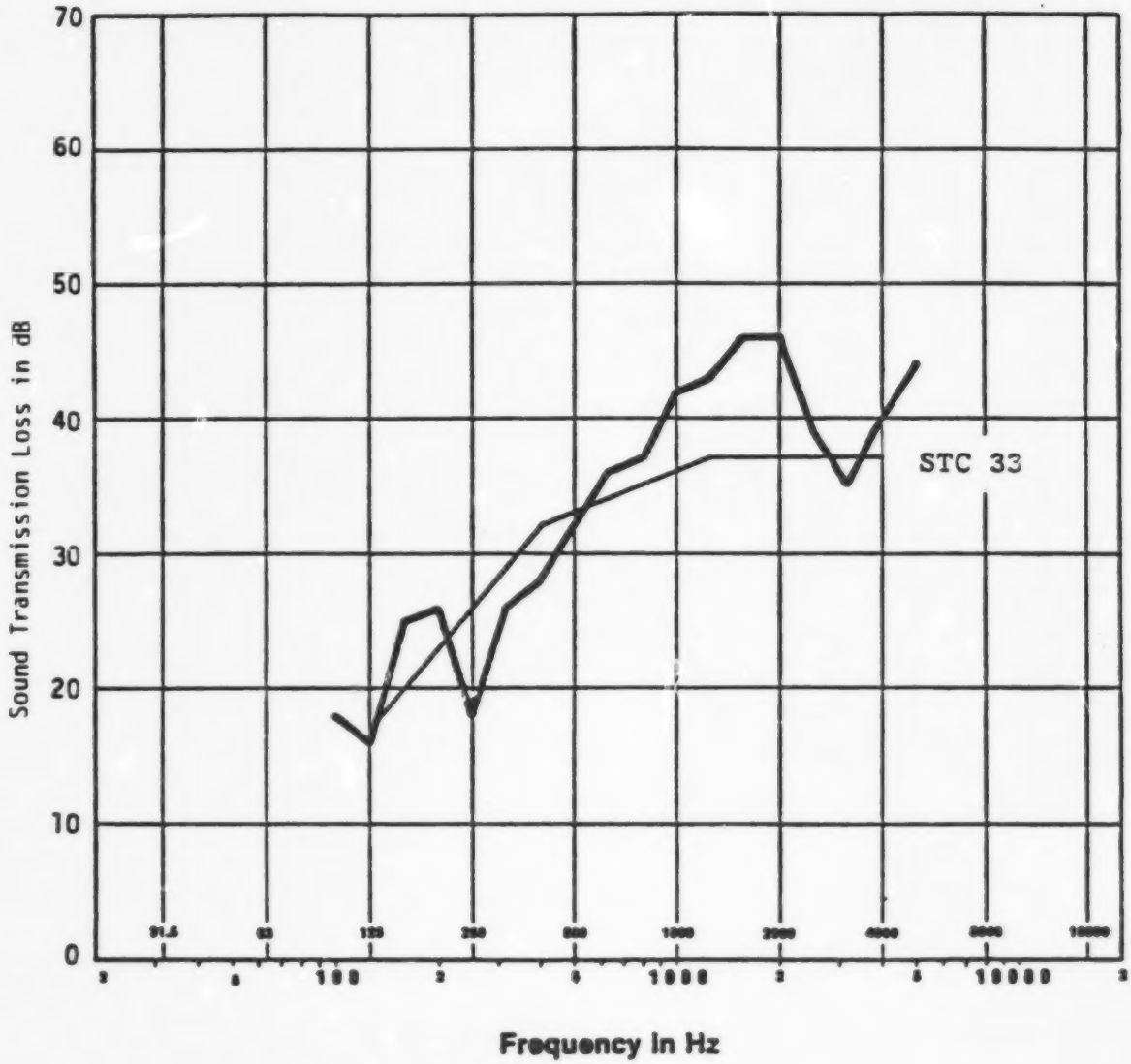


FIGURE B8

Unit X

Single Glazing 5mm

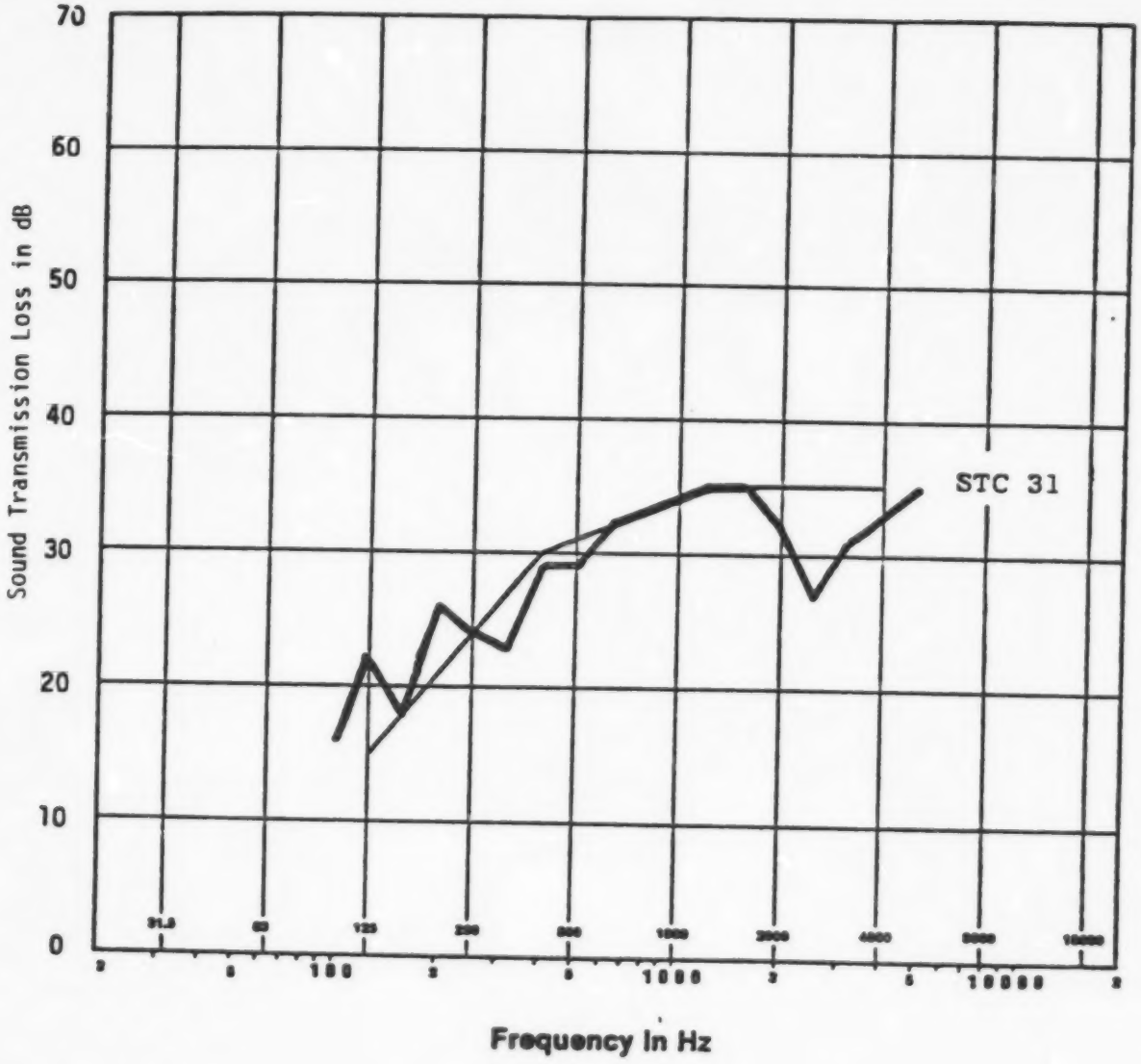
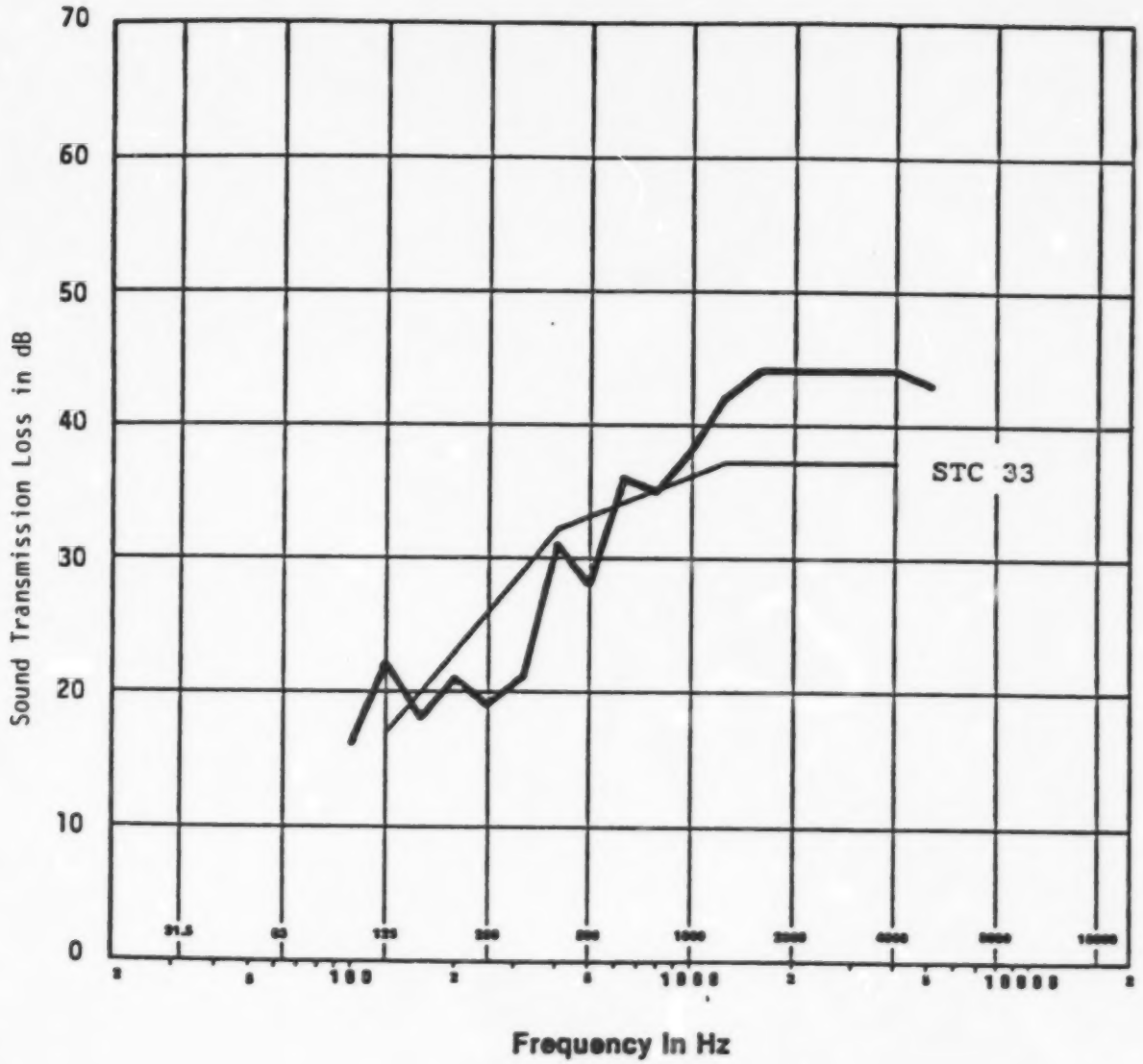


FIGURE B9

Unit Y

Double Glazed Dual Seal 12.7mm Airspace



APPENDIX C

Seal Test Results for: 1 - Double Glazed 12.7 mm Gas Filled
Dual Sealed Unit

1 - Triple Glazed 6.35 mm Gas Filled
Dual Sealed Unit

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PAGES 2
FIGS.
BOOK SERIAL NO. 368TP
BOOK PAGE

REPORT

DOUBLE GLAZED.

REPORT NO. 3303TP
DATE Oct. 3/1983
LAB. ORDER NO BR4895
FILE NO M43-140-1

DIVISION OF BUILDING RESEARCH

SECTION Thermal Performance

FOR Ontario Research Foundation, Building Performance Centre, Sheridan Park Research Community, Mississauga, Ont. L5K 1B3 Attn: Mr. W. Alderson

REFERENCE Application for test dated 31 March 1983

SUBJECT Tests in accordance with specification CAN2-12.8-M76 on "DUAL SEAL", gas filled, double-glazing units supplied by Ontario Research Foundation.

SUBMITTED BY
Asst. SECTION HEAD
K.R. Solvason

APPROVED
Assoc. DIRECTOR
L.W. Gold

AUTHOR H.L. Egan
H.L. Egan

20; 356 mm x 508 mm double-glazing units were received from the manufacturer on May 25/83. The units appeared to be constructed as follows.

Glass - 4 mm
Spacer - 12 mm Hollow Metal Box (Probably filled with desiccant)
Seal - Gray & Black
Edge - Bare Glass

The units were arbitrarily numbered from 1-18 for identification during the tests. In accordance with Specification CAN2-12.8-M76, the following tests were carried out:

1. Initial Seal Test as outlined in paragraph 4.2.1, units 1-18 inclusive;

2. Initial Dew Point Temperature, paragraph 4.2.2, units 1-18 inclusive;

3. Ultraviolet Exposure Fogging Test, paragraph 4.2.3, units 17 & 18;

4. Weather Cycling Test, paragraph 4.2.4, units 1-4 inclusive;

5. High Humidity Cycling, paragraph 4.2.5, units 5-12 inclusive.

The results of the tests are tabulated on page 2.

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DUAL SEAL

RESULTS OF INITIAL SEAL TEST, INITIAL DEW POINT TEMPERATURE, ULTRAVIOLET EXPOSURE FOGGING TEST, WEATHER CYCLING TEST AND HIGH HUMIDITY CYCLING ON SEALED DOUBLE GLAZING UNITS.

RÉSULTATS DE L'ESSAI INITIAL D'ÉTANCHÉITÉ, DE L'ESSAI DE LA TEMPÉRATURE INITIALE DU POINT DE ROSÉE, DE L'ESSAI D'EXPOSITION AUX RAYONS ULTRAVIOLETS PRODUISANT UN BROUILLARD, DE L'ESSAI CYCLIQUE DE TEMPÉRATURE ET DE L'ESSAI DE CYCLAGE A L'HUMIDITÉ ÉLEVÉE QUI ONT ÉTÉ MENÉS SUR DES PANNEAUX A DOUBLES-VITRES SCELLÉS.

Unit No *N° du panneau*	Initial Seal Test *Essai initial d'étanchéité* *	Initial Dew Point *Essai initial de la température du point de rosée* °C **	Dates of Cycling Tests and Fogging Tests *Dates des essais de cyclage et des essais produisant un brouillard*		Number of cycles or days *Nombre de cycles ou de jours* ***	Dew Point After Cycling (°C) ** or Ultra Violet Fogging Result *Point de rosée après le résultat du cyclage(°C)** ou des rayons ultraviolets produisant un brouillard*
			From *Du*	To *Au*		
1	1	NF	Jul.29/83	Sep.23/83	320A	-56
2	1	NF	"	"	320A	-50
3	1	NF	"	"	320A	-61
4	1	NF	"	"	320A	-56
5	1	NF	Jul.25/83	Aug.22/83	224B	-62
6	1	NF	"	"	224B	-62
7	1	NF	"	"	224B	-62
8	1	NF	"	"	224B	-62
9	1	NF	"	"	224B	-60
10	1	NF	"	"	224B	-62
11	1	NF	"	"	224B	-56
12	1	NF	"	"	224B	-59
13	1	NF				
14	1	NF				
15	1	NF				
16	1	NF				
17	1	NF	Sep.22/83	Sep.29/83	7C	No Deposit
18	1	NF	"	"	7C	No Deposit

* 1 - No leakage apparent/*Aucune fuite apparente*

2 - Small leak/*Petite fuite*

3 - Large leak/*Fuite intense*

** N.F. No frost visible with -73 °C Dew Point Apparatus Temperature

A.G. Aucun givre visible d'après l'appareil de mesure de la température du point de rosée à -73 °C

*** A - Cycles of weather cycling test/*Cycles de l'essai cyclique de températures*

B - Cycles of high humidity cycling/*Cycles du cyclage à l'humidité élevée*

C - Days in ultraviolet exposure test/*Nombre de jours de l'essai d'exposition aux rayon ultraviolets*

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PAGES 2
FIGS.
BOOK SERIAL NO. 368TP
BOOK PAGE 192

REPORT

TRIPLE GLAZED

REPORT NO. 3305TP
DATE Oct. 19, 1983
LAB. ORDER NO. BR4895
FILE NO. M43-140-1

DIVISION OF BUILDING RESEARCH

SECTION Thermal Performance

FOR Ontario Research Foundation, Building Performance Centre,
Sheridan Park Research Community, Mississauga, Ontario L5K 1B3
Attention: Mr. W. Alderson

REFERENCE Application for test dated March 31st, 1983.

SUBJECT Tests in accordance with specification CAN2-12.8-M76 on "Dual Seal" gas filled triple-glazing units supplied by Ontario Research Foundation.

SUBMITTED BY
Asst. SECTION HEAD
K.R. Solvason

AUTHOR H.L. Egan

APPROVED
ASSOC. DIRECTOR
L.W. Gold

18; 350 mm x 500 mm triple-glazing units were received from the manufacturer on May 25/83. The units appeared to be constructed as follows:

Glass - 3 - 4 mm
Spacer - 2 - 6 mm Hollow Metal Box (Probably filled with desiccant)
Seal - Gray & Black
Edge - Bare Glass

The units were arbitrarily numbered from 1-18 for identification during the tests. In accordance with Specification CAN2-12.8-M76, the following tests were carried out:

1. Initial Seal Test as outlined in paragraph 4.2.1, units 1-18 inclusive;

2. Initial Dew Point Temperature, paragraph 4.2.2, units 1-18 inclusive;

3. Ultraviolet Exposure Fogging Test, paragraph 4.2.3, units 17 & 18;

4. Weather Cycling Test, paragraph 4.2.4, units 1-4 inclusive;

5. High Humidity Cycling, paragraph 4.2.5, units 5-12 inclusive.

The results of the tests are tabulated on page 2.

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Dual Seal

RESULTS OF INITIAL SEAL TEST, INITIAL DEW POINT TEMPERATURE, ULTRAVIOLET EXPOSURE FOGGING TEST, WEATHER CYCLING TEST AND HIGH HUMIDITY CYCLING ON SEALED TRIPLE GLAZING UNITS.

RÉSULTATS DE L'ESSAI INITIAL D'ÉTANCHÉITÉ, DE L'ESSAI DE LA TEMPÉRATURE INITIALE DU POINT DE ROSÉE, DE L'ESSAI D'EXPOSITION AUX RAYONS ULTRAVIOLETS PRODUISANT UN BROUILLARD, DE L'ESSAI CYCLIQUE DE TEMPÉRATURE ET DE L'ESSAI DE CYCLAGE A L'HUMIDITÉ ÉLEVÉE QUI ONT ÉTÉ MENÉS SUR DES PANNEAUX A TRIPLES-VITRES SCELLÉS

Unit No *N° du panneau*	Initial Seal Test *Essai initial d'étanchéité* *	Initial Dew Point *Essai initial de la température du point de rosée* °C	**	Dates of Cycling Tests and Fogging Tests *Dates des essais de cyclage et des essais produisant un brouillard* From *Du*	To *Au*	Number of cycles or days *Nombre de cycles ou de jours* ***	Dew Point After Cycling (°C) ** or Ultra Violet Fogging Result *Point de rosée après le résultat du cyclage (°C) ** ou des rayons ultraviolets produisant un brouillard*	
1	1	NF	NF	Jul.29/83	Sept23/83	320A	-37	-34
2	1	NF	NF	"	"	320A	-40	-22
3	1	NF	NF	"	"	320A	-45	-40
4	1	NF	NF	"	"	320A	-51	-45
5	1	NF	NF	Jul.25/83	Aug.22/83	224B	-40	-40
6	1	NF	NF	"	"	224B	-40	-40
7	1	NF	NF	"	"	224B	-40	-29
8	1	NF	NF	"	"	224B	-38	-34
9	1	NF	NF	"	"	224B	-40	-37
10	1	NF	NF	"	"	224B	-40	-34
11	1	NF	NF	"	"	224B	-34	-34
12	1	NF	NF	"	"	224B	-34	-34
13	1	NF	NF					
14	1	NF	NF					
15	1	NF	NF					
16	1	NF	NF					
17	1	NF	NF	Sept29/83	Oct. 6/83	7C	No Deposit	
18	1	NF	NF	"	"	7C	No Deposit	

* 1 - No leakage apparent/*Aucune fuite apparente*
2 - Small leak/*Petite fuite*
3 - Large leak/*Fuite intense*

** N.F. No frost visible with -73 °C Dew Point Apparatus Temperature
A.G. Aucun givre visible d'après l'appareil de mesure de la température du point de rosée à -73 °C

*** A - Cycles of weather cycling test/*Cycles de l'essai cyclique de températures*
B - Cycles of high humidity cycling/*Cycles du cyclage à l'humidité élevée*
C - Days in ultraviolet exposure test/*Nombre de jours de l'essai d'exposition aux rayons ultraviolets*

Units undersized as received (350 mm X 500 mm) should have been 355 mm X 510 mm

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